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The Impact of Global Value Chain Production Length on Carbon Emissions in China's Manufacturing Sector

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Abstract. Based on panel data from 15 manufacturing subsectors in China from 1999 to 2020, this paper examines the impact of aggregate Global Value Chain (GVC) production length on manufacturing carbon emissions, utilizing the OECD-ICIO database and CEADs data. The baseline regression results indicate that the extension of both forward and backward GVC production lengths significantly inhibits manufacturing carbon emissions, with estimated coefficients significantly negative. This study provides basic empirical evidence for understanding the low-carbon transition of China's manufacturing sector during its deep integration into global production networks.

Keywords: GVC Production Length; Forward and Backward Linkages; Carbon Emissions; Manufacturing Sector.

1. Introduction

Currently, global climate governance is entering a stage of accelerated implementation, and carbon neutrality has become a global consensus. As a major manufacturing country, China faces dual challenges: international pressure for emission reduction and domestic demand for high-quality development. The deep embedding in the Global Value Chain (GVC) division system is reshaping the production and low-carbon transition paths of China's manufacturing sector.

The academic lineage of GVC theory can be traced back to Porter's (1985) enterprise value chain concept. Subsequently, Kogut (1985) elevated this concept to the macro level by proposing the "value-added chain," emphasizing that countries embed themselves into production stages based on comparative advantages. With the globalization of the spatial layout of production stages, Gereffi (1999) formally proposed the concept of "Global Value Chain" (GVC), defining it as a complex network connecting multinational enterprises and organizations across R&D, production, and final consumption. Entering the 21st century, relevant theories have been further expanded: Kaplinsky (2000) pointed out that multinational enterprises are the key forces driving the formation of GVCs; Sturgeon et al. (2001) constructed a comprehensive analytical framework for GVCs from dimensions such as organizational scale and geographic distribution, clarifying the complex network nature of full-process value-added activities.

The essence of GVCs is the fragmentation of production processes, and the key indicator for measuring this feature is the "production length." It captures the total number of times value-added is counted from initial factor inputs to the absorption of final products (Wang et al., 2017). Existing studies on GVC and carbon emissions mostly focus on the division of labor status or the degree of participation, while discussions on production length as a core feature remain relatively scarce. Therefore, this paper focuses on aggregate GVC production length, utilizing inter-country input-output tables and carbon emission databases to empirically test its fundamental impact on manufacturing carbon emissions.

2. Literature Review and Research Hypothesis

Existing studies have explored the relationship between GVC embeddedness and carbon emissions from various dimensions. From the perspective of GVC division of labor status, Shi et al. (2022)

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found a robust negative correlation between the upgrading of value chain status and carbon emissions, with this effect being particularly significant in developed countries. Wu et al. (2024) found that GVC embeddedness reduces corporate pollution emission levels through scale effects and technological effects. From the perspective of GVC participation degree, Shi et al. (2022) argued that forward participation patterns are more effective in promoting carbon emission reduction than backward participation, especially in developed countries. Li et al. (2023) revealed more complex conclusions: the GVC backward embeddedness mode can improve carbon emission efficiency (CEE), while the forward embeddedness mode inhibits CEE; moreover, as GVC status rises, both forward and backward embeddedness modes exhibit an inverted U-shaped relationship with CEE. Wei et al. (2024) found that GVC backward participation can promote carbon emission reduction in all economies, but forward participation only reduces carbon emissions in developed countries while increasing them in developing countries. From the perspective of GVC production length, Wang et al. (2020) empirically demonstrated an inverted U-shaped relationship between China's manufacturing GVC production length and carbon emissions. Huang et al. (2022) argued that extending GVC production length can significantly promote carbon emission reduction, with the emission reduction effect of extending simple GVC production length being more significant.

The above studies have confirmed the promotional effect of GVC participation on carbon reduction from multiple dimensions. However, unlike traditional indicators that focus on trade scale and embeddedness depth, GVC production length measures the degree of cross-border fragmentation of production processes. Its extension implies more complex international division of labor and more frequent cross-border flows of intermediate goods. This feature enables the extension of GVC production length to not only accelerate green innovation through technology spillovers and learning effects but also promote the upgrading of energy efficiency standards in various stages along longer production chains, thereby forming an additional emission reduction effect at the industrial linkage level that is distinct from simple participation or status upgrading. Therefore, GVC production length, as a core indicator characterizing the essence of GVCs, has an independent inhibitory effect on China's manufacturing carbon emissions. Accordingly, the core hypothesis of this paper is proposed:

The extension of GVC production length significantly inhibits carbon emissions in China's manufacturing sector.

3. Measurement and Evaluation of GVC Production Length and Carbon Emissions in China's Manufacturing Sector

3.1. Measurement and Evaluation of GVC Production Length

3.1.1. Measurement of GVC Production Length

This paper primarily follows the GVC length measurement method proposed by Wang et al. (2017). The total production length is expressed as $Plvy = \frac{\hat{V}BB\hat{Y}}{\hat{V}B\hat{Y}}$, where $\hat{V}$ is the diagonal matrix with the value-added coefficient vector as diagonal elements, and $\hat{Y}$ is the diagonal matrix with final product and service production vector Y as diagonal elements. The numerator represents the total output accumulated along the production chain from value-added, while the denominator represents the value-added contributed from the source country's sector to the final country's sector. The total production length is the number of times value-added is counted from first being used as a primary input to being ultimately absorbed.

By aggregating $Plvy = \frac{\hat{V}BB\hat{Y}}{\hat{V}B\hat{Y}}$ across all products from a source country's sector to the final country (i.e., summing the row of the sector in the matrix), the value-added Va of the sector and the total output Xv it induces can be calculated, thereby deriving the GVC forward production length PL_GVC_f:

$$PL_GVC_f = \frac{Xv_GVC}{Va_GVC} = \frac{\hat{V}LLA^F BYu' + \hat{V}LA^F BBYu'}{\hat{V}LA^F BYu'}. \quad (1)$$

Where the denominator Va_GVC is the value-added of a country's sector participating in GVC production, and the numerator Xv_GVC is the total output induced by the value-added; both numerator and denominator are aggregated based on forward industrial linkages. u is a 1×N row vector with all elements equal to 1, and u' is an N×1 column vector with all elements equal to 1.

By aggregating $Plvy = \frac{\hat{V}BB\hat{Y}}{\hat{V}B\hat{Y}}$ across all sectors of the source country to a specific product in the final country (i.e., summing the column of the product in the matrix), the final production Y of the product and its induced output contribution Xy can be calculated, thereby deriving the GVC backward production length PL_GVC_b:

$$PL_GVC_b = \frac{Xy_GVC}{Y_GVC} = \frac{u\hat{V}LLA^F BY + u\hat{V}LA^F BBY}{u\hat{V}LA^F BY} \tag{2}$$

In the equation, the denominator Y_GVC is the final production of a country's product in GVCs, and the numerator Xy_GVC is the output contribution induced by final production; both are aggregated based on backward industrial linkages.

3.1.2. Data Description

Following the theoretical methods above, this paper selects relevant data from 15 manufacturing subsectors in China from 1999 to 2020. The indicator data for GVC production length is calculated based on the Inter-Country Input-Output (ICIO) tables published by the Organization for Economic Co-operation and Development (OECD-ICIO, 2023 version).

Since the data required for empirical analysis originate from different statistical systems, GVC data are based on the OECD-ICIO international industry classification, while China's manufacturing carbon emissions and related economic data follow the national "Industrial Classification for National Economic Activities" standard. To ensure data consistency at the industry level, this paper matched the two classification standards. The specific matching results are shown in Table 1.

Table 1. Industry Matching Results.

Numble	OECD	ISIC Code
1	C10T12	13-16
2	C13T15	18-19
3	C16	20, 21
4	C17-18	22, 23
5	C19	25
6	C20	26
7	C21	27, 28
8	C22	29
9	C23	30
10	C24	31, 32
11	C25	33
12	C26	39, 40
13	C27	38
14	C28	34, 35
15	C29-30	36, 37

3.1.3. Measurement Results of GVC Production Length

Using OECD input-output table data and Stata software, this paper calculates GVC-related production length data for 15 manufacturing subsectors in China. Figure 1 presents the evolution trend of the mean GVC production length in China's manufacturing sector from 1999 to 2020.

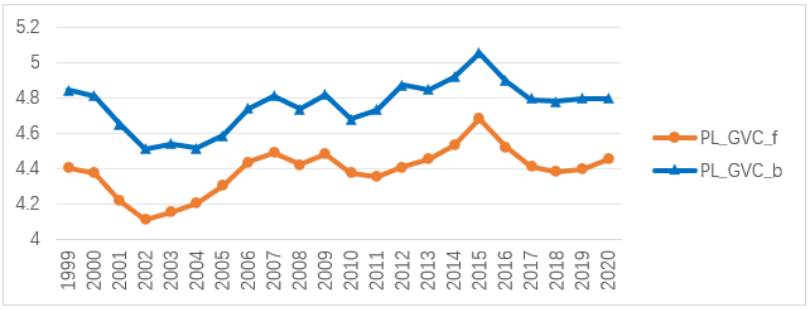


Fig. 1 Line chart showing the annual average
in the length of China's manufacturing global value chain production

As shown in Figure 1, in terms of the overall trend, the GVC forward production length (PL_GVC_f) remained relatively stable during the sample period without significant upward or downward trends. The GVC backward production length (PL_GVC_b) exhibited an inverted U-shaped fluctuation, rising initially and then declining, reaching a peak in 2015 before gradually falling back.

3.2. Measurement and Evaluation of Carbon Emissions

3.2.1. Measurement of Carbon Emissions

The carbon emission data used in this paper is obtained from the Carbon Emission Accounts and Datasets (CEADs), jointly developed by Tsinghua University and other institutions. It is one of the most authoritative and widely covered carbon emission accounting databases in China, extensively used in academic research. The database provides CO2 emission data for China's manufacturing subsectors from 1999 to 2020, measured in million tonnes (Mt), covering emissions from fossil fuel combustion and industrial production processes. The industry classification follows the national standard, which has been matched and unified into 15 manufacturing subsectors, ensuring consistency with the GVC production length data.

3.2.2. Temporal Trends of Carbon Emissions

Summing up the carbon emissions of the 15 subsectors yields the annual trend of total carbon emissions in China's manufacturing sector from 1999 to 2020, as shown in Figure 2.

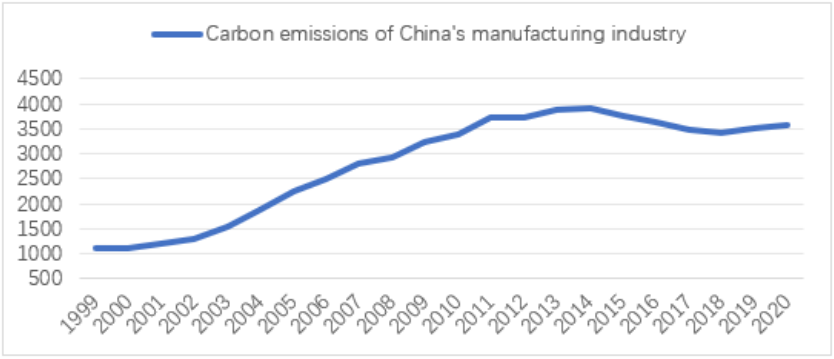


Fig. 2 Line chart showing the annual average change
in carbon emissions of China's manufacturing industry

Overall, the total carbon emissions of China's manufacturing sector experienced an evolution trajectory of "remaining relatively stable initially, experiencing rapid growth, and then stabilizing at a high level" during the sample period. From 1999 to 2002, total emissions remained at 1.1-1.3 billion tonnes with relatively flat growth, consistent with the early stage of GVC embedding. Since 2003, emissions began to climb rapidly, increasing from 1.287 billion tonnes in 2002 to 2.804 billion tonnes in 2007, with an average annual growth rate exceeding 15%. This phase coincided with China's deep integration into global production after joining the WTO. During the 2008 financial crisis, the growth

rate temporarily slowed, but emissions quickly resumed growth under policy stimulus, peaking at 3.903 billion tonnes in 2014. After 2015, emissions showed a fluctuating downward trend, decreasing from 3.762 billion tonnes in 2015 to 3.426 billion tonnes in 2018, and slightly rebounding to 3.556 billion tonnes in 2020. Overall, emissions more than doubled from 1.123 billion tonnes in 1999, reflecting that manufacturing remains a key emission sector, though the decline after 2015 indicates initial progress in carbon reduction.

4. Research Design and Data

4.1. Model Construction

To empirically test the impact of GVC production length on carbon emissions, this paper constructs the following econometric model:

$$PCE_{\mathrm{it}} = \alpha_0 + \alpha_1 PL_GVC_f_{it} + \alpha_2 PL_GVC_b_{it} + \sum \alpha_j X_{it} + \mu_i + \gamma_t + \varepsilon_{it} . \quad (3)$$

Where subscripts i and t denote industry and year, respectively. PCE_{it} represents the per capita carbon emissions of industry i in year t. The core explanatory variables are the GVC production lengths, including forward (PL_GVC_f) and backward (PL_GVC_b) lengths. X_{it} is a vector of control variables including ownership structure, energy consumption structure, foreign investment penetration, and environmental regulation intensity. μ_i is the industry fixed effect, γ_t is the year fixed effect, and ε_{it} is the random error term.

4.2. Variable Description

This paper selects panel data from 15 manufacturing subsectors from 1999 to 2020. GVC production length data comes from the measurements in Section 3; carbon emission data is from CEADs; and other data are from various statistical yearbooks. Variable definitions are as follows:

4.2.1. Dependent Variable

Manufacturing per capita carbon emissions (PCE): Calculated as the ratio of carbon emissions to employment in each industry, measured in million tonnes per ten thousand people, reflecting the emission level of each subsector.

4.2.2. Core Explanatory Variables

Following Wang et al. (2017), the selected GVC production length indicators include:

(1) GVC forward production length (PL_GVC_f): Based on forward industrial linkages, measuring the total number of stages a sector's value-added undergoes from being created to being completely absorbed as intermediate inputs in other countries.

(2) GVC backward production length (PL_GVC_b): Based on backward industrial linkages, measuring the total number of stages domestic and foreign value-added undergo from initial inputs to final outputs in a sector's production.

4.2.3. Control Variables

(1) Ownership Structure (PRS): The proportion of employment in state-owned enterprises to total employment.

(2) Energy Consumption Structure (ECS): The proportion of coal consumption to total energy consumption.

(3) Foreign Investment Penetration (FIP): The ratio of fixed assets of foreign-funded enterprises to total fixed assets.

(4) Environmental Regulation Intensity (ER): The ratio of operating costs of pollution control facilities to total costs.

5. Empirical Results Analysis

5.1. Descriptive Statistics

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

Table 2. Descriptive Statistics of Main Variables.

Variable	Obs	Mean	Std.Dev.	Min	Max
PCE	330	0.439	0.810	0.004	4.882
PL_GVC_f	330	4.389	0.554	3.157	5.923
PL_GVC_b	330	4.759	0.476	2.976	5.538
PRS	330	0.221	0.185	0.013	0.782
ECS	330	0.399	0.321	0.003	1.768
FIP	330	0.288	0.140	0.046	0.789
ER	330	0.003	0.005	0.000	0.029

5.2. Baseline Regression Results

Based on the theoretical analysis and research design, this paper uses the two-way fixed effects model to estimate Equation (3) using panel data from 15 manufacturing subsectors from 1999 to 2020. The results are shown in Table 3.

Table 3. Baseline Regression Results

Variable	PCE
PL_GVC_f	-0.290***
	(-3.60)
PL_GVC_b	-0.566***
	(-4.62)
PRS	-0.582
	(-0.95)
ECS	0.551***
	(2.99)
FIP	0.150
	(0.31)
ER	23.403***
	(2.83)
Industry FE	Yes
Year FE	Yes
F-statistic	11.519***
R-squared	0.478
N	330

*Note: t-statistics in parentheses. ***, *, and * denote significance at the 1%, 5%, and 10% levels, respectively.

Table 3 reports the impact of GVC forward (PL_GVC_f) and backward (PL_GVC_b) production lengths on manufacturing per capita carbon emissions. The results show that the estimated coefficient of PL_GVC_f is -0.290, significant at the 1% level; and the coefficient of PL_GVC_b is -0.566, also

significant at the 1% level. This indicates that for every 1-unit extension of PL_GVC_f, per capita carbon emissions decrease by approximately 0.290 units; for every 1-unit extension of PL_GVC_b, emissions decrease by approximately 0.566 units.

In terms of direct mechanisms, the extension of GVC forward length means that China's manufacturing sector extends to upstream links such as R&D and design, which inherently have higher value-added and lower energy intensity, thus directly reducing per capita emissions. The extension of GVC backward length reflects the expansion of intermediate goods imports and processing assembly. Its emission reduction effect may stem from the substitution of high-tech, high-environmental-standard imported intermediates for domestic high-energy-consuming production stages, as well as the optimization of specialized division of labor brought by scale expansion. Comparatively, the absolute value of the coefficient for backward length is larger than that for forward length, indicating that backward linkage participation had a more prominent direct pulling effect on carbon reduction in China's manufacturing sector during the sample period.

The baseline regression results demonstrate that the extension of GVC production length significantly inhibits carbon emissions.

6. Conclusion

Using panel data from 15 manufacturing subsectors in China from 1999 to 2020, this paper empirically examines the impact of aggregate GVC production length on carbon emissions. The study finds that the extension of both forward and backward GVC production lengths significantly inhibits manufacturing carbon emissions. This basic conclusion indicates that China's manufacturing sector can effectively promote its low-carbon transition during the process of deep embedding into global value chains and extending production chains.

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