UNIVERSITY OF GOTHENBURG
SCHOOL OF BUSINESS, ECONOMICS AND LAW

How Does the Position in Global Value Chain Affect Gross National Income

Jianwei Li

Supervisor: Björn Tyrefors
Master's thesis in Economics, 30 hec
Spring 2025
Graduate School, School of Business, Economics and Law, University of Gothenburg, Sweden

Master's Thesis in Economics

How Does the Position in Global Value Chain Affect Gross National Income

Jianwei Li

May 2025

UNIVERSITY OF GOTHENBURG
SCHOOL OF BUSINESS, ECONOMICS AND LAW

Abstract

This paper studies whether there is a nonlinear positive U-shaped relationship between the impact of the global value chain (GVC) position index at the national level and the gross national income per capita (GNI), and analyzes the impact of the GVC position index of different industries on the GNI per capita. The study uses national-level panel data, covering data from 40 countries from 1996 to 2020, including 20 high-income countries and 20 low-income countries. The results show that the GVC position index at the national level has a positive U-shaped nonlinear relationship with GNI. And the increase in the GVC position of the secondary industry has significantly improved the GNI of both high-income and low-income countries. This study provides new empirical evidence for understanding the nonlinear and heterogeneous economic effects of GVC participation.

Keywords: global value chain · gross national income · nonlinearity · sectoral heterogeneity · fixed effects model

Contents

List of Tables 2

List of Figures 2

1 Introduction 3

2 Literature Review 4

3 Theory and Hypothesis 5

4 Data 6

4.1 Data Description and Variable Definitions 6

4.2 Justification of Control Variable 9

4.3 Global Value Chain Position Index 11

4.3.1 GVC Position Index at Economic-Activity Level 11

4.3.2 GVC Position Index at Country Level 11

4.3.3 GVC Forward and Backward Participation Index 12

4.3.4 GVC Forward and Backward Participation Index at Country Level 13

4.3.5 GVC Position Index at Sector Level 13

4.4 Composite Trade Share 14

5 Empirical Methodology 14

5.1 Main Estimation Model 14

5.2 Heterogeneity Analysis 16

5.3 Model Diagnostics 16

6 Result and Analysis 18

6.1 Result of Global Value Chain Position Regression 19

6.2 Result of Global Value Chain Participation Regression 20

6.3 Result of Sectoral Global Value Chain Position Regression 22

6.4 Robustness Test 22

7 Discussion and Conclusion 25

Reference 28

Appendix 32

List of Tables

1 Descriptive Statistics 8
2 Variable Name and Abbreviation 9
3 Fixed Effects Regression of the Effect of GVC Position on GNI by Income-Level Group 19
4 Fixed Effects Regression of the Effect of GVC Participation on GNI by Income-Level Group 20
5 Fixed Effects Regression of the Effect of Sectoral GVC Position on GNI by Income-Level Group 22
6 Robustness Test of the Effect of GVC Position on GNI 23
7 Robustness Test of the Effect of GVC Participation on GNI 24
8 Robustness Test of the Effect of Sectoral GVC Position on GNI 25
A1 Economic Activities Classified by ISIC Rev.4 33
A2 List of Countreis Grouped by Income Level 33
A3 Hausman Tests for Model Specification 34
A4 Breusch-Pagan Tests for Heteroskedasticity 34
A5 Breusch-Godfrey Tests for Serial Correlation 35
A6 Breusch-Pagan LM Tests for Cross-Sectional Dependence 35

List of Figures

1 Causal Diagram 9
A1 Geographic Distribution of Sample Countries by Income Group 32

1 Introduction

In recent years, the global value chain (GVC) has significantly changed the structure of international trade and value distribution. Instead of exporting complete goods, countries now specialize in specific stages of production such as raw materials, assembly, or branding, and participate in international production networks in a fragmented way (Gereffi, 1994; Timmer et al., 2014). Under this background, the position of a country in the value chain has become an important factor that may affect how much value it can capture from global trade.

Although the positive effects of GVC participation on economic growth have been widely discussed, most existing studies treat GVC engagement as a binary or linear variable (World Bank, 2020), and they rarely investigate the relationship between GVC position and income in a structural way. Some studies suggest that countries located at either end of the value chain, upstream (e.g., resource exporters) or downstream (e.g., branding and R&D), may capture more value than those stuck in the middle (e.g., assembly) (Pipkin and Fuentes, 2017). However, there is still a lack of systematic empirical research on this possible nonlinear pattern. In addition, whether a country can benefit from GVC participation also depends on its domestic conditions, such as institutional quality and human capital, but these factors are not fully considered in previous studies.

This work aims to address these shortcomings. Using a data set of 40 countries from 1995 to 2020, we aggregate a country-level index of global value chain (GVC) position based on data at economic activity level. We introduce four control variables considered as confounders: government effectiveness, average years of schooling, natural resource endowment, and trade openness.

We explore the impact on gross national income per capita (GNI), which is used here as a proxy for standard of living, from three perspectives. The first one is about the GVC index at the country level and tests its nonlinear relationship with GNI using a squared term. We incorporate both forward and backward GVC participation in the model and test their interaction. Finally, the GVC positions of the three main sectors (primary sector, secondary sector, and tertiary sector) will also be taken into consideration. The main empirical method is to use a fixed effect panel regression. We also conduct heterogeneity analysis with group countries by income level. To account for potential OLS assumption violations, we adopt the fixed effect model with Driscoll-Kraay standard errors for accurate estimation.

The results show that the global value chain position and per capita national income show a clear positive U-shaped relationship, that is, countries at the end of the global value chain tend to have higher income levels than those in the middle. This alue is usually concentrated in the upstream and downstream stages. This also supports the view of Pipkin and Fuentes (2017) that intermediate locations bring greater climbing

challenges.In addition, the positive U-shaped effect is more significant in countries with higher institutional quality and human capital, indicating that national absorptive capacity plays an important role in translating global value chain participation into real income growth.

In summary, this study constructs a multidimensional framework that links the structure, institutions and human capital of global value chains. This book contributes to the existing trade and development literature and provides useful insights for developing countries to avoid the mediocrity trap and advance in global value chains.

2 Literature Review

The theory of Global Value Chains (GVC) was developed to explain the increasingly fragmented nature of global production. Unlike traditional trade theories that focus on final goods, GVC theory emphasizes task specialization across countries based on comparative advantage. Gereffi (1994) laid the foundation by distinguishing between producer-driven and buyer-driven chains, providing a framework for understanding how power and value are distributed within international production networks.

As the theory evolved, scholars began to explore how countries or firms could shift into higher value-added positions, a process commonly referred to as upgrading. Humphrey and Schmitz (2002) identified four main types of upgrading: process, product, functional, and inter-chain. This framework has been widely adopted in later works, including Pipkin and Fuentes (2017), who argue that upgrading from low-end assembly to more sophisticated activities like branding, design, and R&D is essential for increasing value capture. Governance structures also play a critical role in shaping upgrading possibilities. Firms operating under modular governance systems are more likely to innovate independently, while captive systems often limit such potential (Ding, 2008).

Building on these foundations, more recent studies have emphasized the structural and institutional barriers that developing countries face in their upgrading efforts. De Marchi and Alford (2021) highlight the importance of effective industrial policies, particularly those aimed at supplier development and innovation, as key to escaping low-end traps. They also stress the need for policy coherence and coordination across sectors. This reflects a broader shift in the literature, moving from purely economic explanations to more integrated frameworks that include governance, geography, and institutional context.

Mahutga (2012) introduced the concept of GVC spatialization, which focuses on how entry barriers and supplier capabilities influence the expansion of value chains across different industries. Drawing on both Global Commodity Chains (GCC) and GVC governance models, Mahutga shows that the geographic location of lead firms and the mode of chain control together shape global production systems.

In terms of methodology, GVC studies have employed a variety of approaches, including case studies, social network analysis, and panel data regression (Mahutga, 2012; De Marchi and Alford, 2021). However, many existing studies either rely on descriptive typologies or lack the econometric tools needed for causal identification. Few studies attempt to model nonlinear relationships or examine how structural position affects economic outcomes in a systematic way. This study seeks to address these gaps by constructing a continuous GVC participation index, using U-shaped terms to capture nonlinear effects, and applying interaction terms along with instrumental variable techniques to account for endogeneity. These tools allow us to quantify structural nonlinearity and uncover heterogeneity in income effects across different national settings.

While existing research has improved our understanding of GVC structure, governance, and upgrading, most studies do not directly assess the income implications of a country's specific position within the value chain. This study contributes to the literature by explicitly modeling the nonlinear relationship between GVC positioning and national income. It also examines how institutional quality and human capital influence the strength and direction of these effects.

In summary, although the literature provides a multidimensional view of GVC, there is still limited knowledge about how a country's exact chain position influences income in a nonlinear manner. This study builds on existing theoretical foundations and offers new empirical evidence on the joint effects of structural position, institutional quality, and human capital on GVC-related income outcomes.

3 Theory and Hypothesis

Gereffi (1994) first proposed the concept of global value chain (GVC) and used it as an analytical framework to examine the geographical and organizational fragmentation of cross-border production activities. In this framework, there are different production links from raw material extraction, intermediate product manufacturing to final assembly, brand building and after-sales service. The driving force of international trade has gradually shifted from final products to task division and added value contribution.

However, the value distribution between different sectors in the GVC system is not balanced. Gereffi, Humphrey and Sturgeon (2005) put forward a view that emphasizes that when a product passes through the global production process, the added value left at various points in the process is unevenly distributed along the global value chain. The upstream and downstream of the global value chain are usually knowledge-intensive or brand-intensive, while the midstream presents labor-intensive standardized manufacturing and assembly. Therefore, the added value of the upstream and downstream is generally higher than that of the midstream.

Furthermore, Kaplinsky (2000) proposed the concept of rent capture, which means

that companies that control the two ends of GVC can often obtain excess profits from the production process. That is to say, the uneven distribution of value added is not only related to technological capabilities, but also intellectual property rights, standard setting rights and brand control are also major institutional factors, which further aggravates structural inequality.

Mudambi (2008) modeled the above phenomenon and modeled the value added levels of different links in the GVC as a positive U-shaped structure. Value added is an important component of gross national income (GNI) and reflects the income generated by domestic production. By participating in high value-added production, countries will significantly increase their income. However, if a country focuses on low value-added production in the middle of the global value chain, income growth will be limited. In summary, the theoretical framework shows that there is a nonlinear relationship between a country's global value chain position and per capita gross national income, and countries at the two ends of the value chain (upstream or downstream) enjoy higher national income than midstream countries (Timmer et al., 2014).

Based on the above theoretical viewpoints, this study proposes the following hypothesis: There is a positive U-shaped relationship between a country's global value chain position and its per capita gross national income. The closer the country is to the two ends of the GVC, the higher the per capita income level.

4 Data

4.1 Data Description and Variable Definitions

This study uses panel data covering 40 countries (20 high-income countries and 20 middle-income countries) from 1995 to 2020. Due to differences in data availability for different indicators, the observation year ranges of various variables are not consistent. Specifically, the data years available for gross national income per capita (GNI) are 1998, 2000, 2002, and 2004 to 2020 (a total of 20 years). The data years for the global value chain (GVC) position index and GVC-related (all independent variables) include 1997, 1999, 2001, and 2003 to 2019. The data years for government efficiency (GE), average years of education (AYS), and trade openness (CTS) are 1996, 1998, 2000, and 2002 to 2018. The data years for natural resource rent (NRE) are 1993, 1995, 1997, and 1999 to 2015.

The selection of the years above is based on the availability of the data itself, especially the fact that GE is missing a lot in some years. In addition, when constructing the final estimation sample, the lag period set for each variable is also taken into consideration to reduce the endogeneity and reverse causality problems. The basis for setting these lag periods will be further explained in detail at the beginning of Section 6.

Gross national income per capita(GNI), sourced from the World Bank (2025), serves

as the dependent variable. It is measured in per thousand 2021 international US dollars and adjusted for purchasing power parity (PPP) to ensure cross-country comparability.

Government effectiveness (GE) reflects perceptions of the quality of public services, the independence of the civil service from political pressures, the quality of policy formulation and implementation, and the credibility of government commitments. This indicator, ranging from approximately -2.5 to 2.5, is used as a control variable for institutional quality. The data are obtained from the World Bank (2025), following the methodology developed by Kaufmann, Kraay, and Mastruzzi (2010).

Natural resource endowment (NRE) is measured by the share of total natural resource rents in GDP. It includes oil rents, natural gas rents, coal rents, mineral rents, and forest rents. This indicator captures the extent to which a country's economy relies on non-renewable and exhaustible natural resources. The data are obtained from the World Bank (2025).

Education is represented by the average years of schooling (AYS) completed by adults aged 25 and above. The data are collected from the United Nations Development Programme (UNDP, 2025) and reflect the average formal educational attainment of the adult population.

The GVC position at the country level is calculated as a weighted average of industry-level GVC positions. The weights reflect each industry's contribution to the national economy. Sector classifications follow the ISIC Rev.4 standard issued by the United Nations (Department of Economic and Social Affairs, 2008). The required trade value-added data are sourced from the OECD TiVA database (2025).

Table 1. Descriptive Statistics

	Mean	Stand. Dev.	Min	Max
Full sample				
Gross national income per capita	30.81	21.60	1.58	86.79
GVC position	0.20	0.12	−0.12	0.47
GVC forward participation	0.47	0.10	0.23	0.76
GVC backward participation	0.20	0.08	0.05	0.46
Government effectiveness	0.59	0.96	−1.21	2.35
Average years of schooling	9.33	3.10	1.38	14.13
Natural resource endowment	3.24	4.32	0.01	33.25
Composite trade share	2.69	3.31	0.02	15.13
GVC position of the primary sector	0.01	0.02	0.00	0.12
GVC position of the secondary sector	0.04	0.06	−0.13	0.23
GVC position of the tertiary sector	0.09	0.04	−0.03	0.02
High income				
Gross national income per capita	49.42	13.73	16.72	86.79
GVC position	0.19	0.10	−0.02	0.45
GVC forward participation	0.48	0.09	0.35	0.75
GVC backward participation	0.21	0.07	0.06	0.38
Government effectiveness	1.44	0.48	0.19	2.35
Average years of schooling	11.54	1.54	6.31	14.13
Natural resource endowment	1.57	2.83	0.01	17.35
Composite trade share	4.30	3.52	0.45	15.13
GVC position of the primary sector	0.01	0.01	0.00	0.03
GVC position of the secondary sector	0.04	0.05	−0.07	0.23
GVC position of the tertiary sector	0.10	0.04	0.04	0.22
Middle income				
Gross national income per capita	12.20	7.19	1.58	29.78
GVC position	0.20	0.13	−0.12	0.47
GVC forward participation	0.46	0.12	0.23	0.76
GVC backward participation	0.19	0.08	0.05	0.46
Government effectiveness	−0.25	0.42	−1.21	1.02
Average years of schooling	7.13	2.68	1.38	12.21
Natural resource endowment	4.91	4.88	0.19	33.25
Composite trade share	1.07	2.07	0.02	12.00
GVC position of the primary sector	0.02	0.02	0.00	0.12
GVC position of the secondary sector	0.03	0.07	−0.13	0.18
GVC position of the tertiary sector	0.09	0.04	−0.03	0.18

The definitions and abbreviations of all variables used in this study are summarized in Table 2, and the selection of control variables is based on theoretical considerations and further supported by a causal diagram, as discussed in the next section.

Table 2. Variable Name and Abbreviation

Variable Name	Abbreviation
Gross national income per capita	GNI
Global value chain position	$GVC_{position}$
Global value chain forward participation	$GVC_{forward}$
Global value chain backward participation	$GVC_{backward}$
Government effectiveness	GE
Average years of schooling	AYS
Natural resource endowment	NRE
Composite trade share	CTS
Global value chain position of the primary sector	$GVC_{primary}$
Global value chain position of the secondary sector	$GVC_{secondary}$
Global value chain position of the tertiary sector	$GVC_{tertiary}$

4.2 Justification of Control Variable

Besides GVC position index and GNI, we select four confounders as control variable, which correspond variable B in Figure 4.2. The four confounders include composite trade share, natural government effectiveness, education, and natural resource rent as a share of GDP.

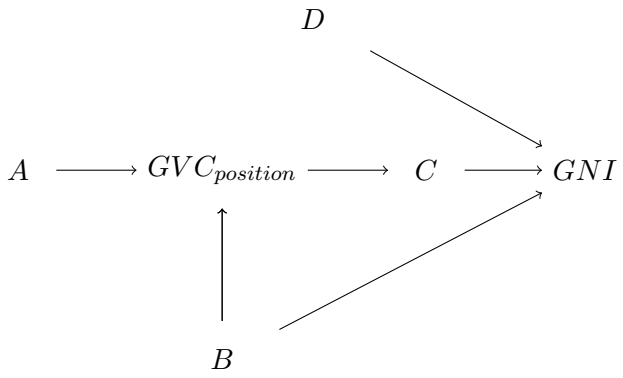

Figure 1. Causal Diagram

Many studies support the impact of government efficiency (GE) on GVCs and GNI. Acemoglu, Johnson, and Robinson (2001) emphasize that the quality of enterprises, including GE, is a fundamental driver of long-term economic growth, which indirectly increases GNI by ensuring stable property rights and good public management. Taglioni and Winkler (2016) extend this framework to link GE to GVC participation, arguing that effective governance can attract foreign investment, promote technological spillovers, and create skilled jobs, thereby improving GVC position. UNCTAD (2021) emphasizes the role of digital governance in modern GVCs and cites examples such as Singapore's "one-stop" trading platform, which reduces customs clearance time from days to minutes, showing how digital reforms driven by GE reduce trade barriers and improve GVC effi-

ciency. Overall, these studies show that globalization not only maintains macroeconomic outcomes (GNI), but also enables deeper and more competitive participation in GVCs through institutional stability, policy consistency, and technological innovation.

Education plays an important role in influencing a country's GVC position and income level. Countries with higher average education levels are more likely to have a workforce that is better able to participate in the upstream and higher value-added parts of the global value chain. Raei, Ignatenko, and Mircheva (2019) identified average years of education as a key indicator of human capital in the production function model. They found that higher education improves participation in global value chains by strengthening vocational skills, promoting the adoption of new technologies, and facilitating the modernization of production networks. Similarly, the OECD (2017) showed that the widespread provision of basic education and vocational training helps to cultivate a skilled workforce, enabling countries to adapt to rapid changes in global production and engage in more complex work. At the same time, average years of education is also considered a fundamental factor in determining national income. UNDP (2024) considers the number of years of education as an important factor affecting a country's income level. In addition, Hanushek and Wosman (2008) showed that the quantity and quality of education have a significant impact on long-term economic growth. Specifically, the accumulation of learning can enhance human capital, enable employees to perform better, and adapt to technological and structural changes. Therefore, education, measured by average years of schooling, is a confounding factor affecting GVC participation and national income expansion because it affects labor productivity and institutional capacity.

Dependence on natural resource extraction affects a country's position in the global value chain and its gross national income. Ross (2015) pointed out that countries with a high rent-to-GDP ratio tend to experience deindustrialization, which reduces the competitiveness of their manufacturing industry in the global value chain. This situation leads to a reduction in the growth of gross national income in developing countries. The resource curse hypothesis proposed by Sachs and Warner (1995) better explains the low economic growth rate in resource-rich countries. The crowding-out effect causes the resource sector to hinder the development of manufacturing and technology, thereby reducing economic diversity. In addition, the "Dutch disease" model proposed by Cordon and Neary (1982) illustrates that resource booms trigger currency appreciation, which may subsequently reduce the competitiveness of exports. Resource-dependent countries are locked in low value-added sectors of the global value chain (such as raw material exploration), hindering the development of high value-added industries and undermining the sustainable growth of gross national income.

Both theoretical and empirical studies show that trade openness has a positive impact on global value chains and national income. Baldwin (2016) argues that trade facilitation, especially in the digital age, lowers barriers to entry into global value chains by creating

real-time cross-border data flows and simplifying customs procedures, thereby attracting cross-border investment and increasing the added value of global value chains. Antras and Chor (2021) say this leads to measurable economic benefits: their analysis of cross-national data shows that for every 1

4.3 Global Value Chain Position Index

4.3.1 GVC Position Index at Economic-Activity Level

The GVC position index at economic-activity level $GVC_{position;ict}$, proposed by Koopman et al. (2010), measures the relative position of economic activity c in country i within the global value chain at time t. Its formula is defined as Equation 1:

$$GVC_{position;ict} = \ln\left(1 + \frac{IV_{ict}}{E_{ict}}\right) - \ln\left(1 + \frac{FV_{ict}}{E_{ict}}\right) \tag{1}$$

where IV_{ict} represents the indirect value added of economic activity c in country i at time t, which refers to the domestic value added contribution indirectly generated through production activities in other countries. FV_{ict} denotes the foreign value added of economic activity c in country i at time t, representing the value contributed by imported intermediate goods and services embedded in the economic activity's exports. E_{ict} denotes the gross exports of economic activity c in country i at time t, representing the total value of goods and services exported by the sector, including both domestic and foreign value added. Therefore, $E_{ict} = DV_{ict} + FV_{ict}$.

The logarithmic transformation in Equation 1 avoids mathematical risks such as zero or negative denominators, ensuring computational robustness. After logarithmic transformation, the value of GVC is in the range of $[-\ln 2, \ln 2]$, that is, $GVC_{position;ict} \in [-\ln 2, \ln 2]$. Additionally, the logarithmic transformation mitigates the distortionary effects of outliers, aligning the index more closely with real-world economic implications.

4.3.2 GVC Position Index at Country Level

The GVC position index at country level $GVC_{position;it}$ is an indicator that quantitatively measures the overall relative position of a country i within the international division of labor system at time t. It reflects the competitive advantages and strategic positions of the entity compared to other economies in the global value chain. The formula for $GVC_{position;it}$ is defined as Equation 2:

$$GVC_{position;it} = \sum_{c} w_{ict} \cdot GVC_{position;ict} \tag{2}$$

where w_{ict} denotes the weight of economic activity c at time t, indicating the importance of economic activity c to the country i. $GVC_{position;ict}$ is defined as the GVC position index of economic activity c in country i at time t. Since the index is essentially obtained by weighting the logarithm, its theoretical value range is still $[-\ln 2, \ln 2]$, that is, $GVC_{position;it} \in [-\ln 2, \ln 2]$.

The weight w_{ict} is used to measure the importance of economic activity c's participation in GVC for country i at time t. It is calculated based on the proportion of domestic value added in total exports for economic activity c of country i at time t, with the formula defined as Equation 3:

$$w_{ict} = \frac{DV_{ict}}{\sum_s DV_{ict}} \tag{3}$$

where DV_{ict} denotes the domestic value added of economic activity c in country i at time t, representing the value generated within the country through domestic production and embedded in exports.

When measuring the importance of an economic activity to a country's exports, early studies widely adopted gross exports as the basis for calculating weights (Hummels, Ishii and Yi, 2001). Equation 4 shows the case in this article. However, since gross exports include the repeated cross-border value of imported intermediates, they may systematically overestimate the weights of low value-added economic activities (Koopman et al., 2010). One solution is to adopt domestic value added as a superior indicataor, which quantifies the contribution of domestic production to gross exports by excluding the value of imported intermediates (Timmer et al., 2014).

$$w_{ict} = \frac{E_{ict}}{\sum_c E_{ict}} \tag{4}$$

4.3.3 GVC Forward and Backward Participation Index

The index $GVC_{position;ict}$ is derived from both forward and backward participation components, which we describe in more detail in this section.

$GVC_{forward;ict}$ and $GVC_{backward;ict}$ indicate the forward and backward GVC participation indices of economic activity c in country i at time t, which are defined as Equation 5 and 6:

$$GVC_{forward;ict} = \frac{IV_{ict}}{E_{ict}} \tag{5}$$

$$GVC_{backward;ict} = \frac{FV_{ict}}{E_{ict}} \tag{6}$$

$GVC_{forward;ict}$ and $GVC_{backward;ict}$ reflect different aspects of an economic activity's participation in GVC. A high $GVC_{forward;ict}$ indicates the economic activity's involvement in upstream activities, such as supplying intermediate goods for further processing abroad. In contrast, a high $GVC_{backward;ict}$ suggests a sector's reliance on imported intermediate

inputs for processing or assembly, placing it in downstream segments typically associated with low value-added production (Koopman et al., 2010).

While these indices measure distinct dimensions of GVC participation, their absolute values should be interpreted in relation to each other. High values in both indices suggest that an economic activity is deeply integrated into the global production network, both as a supplier of intermediate goods (upstream) and as a user of foreign inputs (downstream).

4.3.4 GVC Forward and Backward Participation Index at Country Level

In addition to the aggregation of the economic-activity level GVC position index $GVC_{position;ict}$, this study also constructs country-level indices for forward and backward participation. These indices are used to separately capture the upstream and downstream involvement of a country in GVC.

The aggregation is conducted using the same weighting scheme as in Equation 3, where the weight w_{ict} refers to the share of domestic value added by economic activity c in country i at time t. Specifically, the forward participation index at the country level is calculated as Equation 7:

$$GVC_{forward;it} = \sum_{c} w_{ict} \cdot GVC_{forward;ict} \tag{7}$$

Similarly, the backward participation index is calculated as Equation 8:

$$GVC_{backward;it} = \sum_{c} w_{ict} \cdot GVC_{backward;ict} \tag{8}$$

Using a consistent weighting method allows for comparability across different GVC indicators. Although alternative schemes based on the share of IV_{ict} or FV_{ict} could be considered, this paper adopts the domestic value-added share in order to maintain consistency and clarity in the interpretation of results.

4.3.5 GVC Position Index at Sector Level

Furthermore, we construct sector-level GVC position indicators at the country level by aggregating economic-activity level indices using value-share weights. For country i at time t, the GVC position of sector $s \in \{primary, secondary, tertiary\}$ is calculated as:

$$GVC_{s;it} = \sum_{c \in s} w_{ict} \cdot GVC_{position;ict} \tag{9}$$

where $w_{ict} = \frac{DV_{ict}}{\sum_{c \in s} DV_{ict}}$, and $c \in s$ indicates that economic activity c belongs to sector s. The classification of economic activities into the three sectors follows the standard ISIC Rev.4 mapping, as listed in Table A1. Specifically, the set *primary* includes all economic

activities assigned to the primary sector (e.g., agriculture, fishing, mining); *secondary* contains manufacturing, construction, and utilities; *tertiary* consists of service-related activities.

4.4 Composite Trade Share

The composite trade share (CTS) captures both a country's share in global trade and its trade-to-GDP ratio. Following Squalli and Wilson (2011), CTS for country i at time t is defined as Equation 10

$$CTS_{it} = \frac{(X+M)_{it}}{\frac{1}{n}\sum_{j=1}^{n}(X+M)_{jt}} \cdot \frac{(X+M)_{it}}{GDP_{it}} \tag{10}$$

where X and M denote exports and imports, respectively. n is the number of countries. $(X+M)_{it}$ represents the total trade volume of country i at time t, and GDP_{it} denotes its gross domestic product. The first term in Equation (10) indicates a country's share of global trade volume, while the second term reflects the trade-to-GDP ratio, capturing trade dependence.

For comparison, Equation 11 shows the traditional trade share, which is widely used as a one-dimensional proxy for trade openness (Squalli and Wilson, 2011):

$$TS_{it} = \frac{(X+M)_{it}}{GDP_{it}} \tag{11}$$

The composite trade share adopt a multidimensional approach by taking a country's relative position in global trade into consideration. This is especially crucial for big economies like the US, which, despite their substantial contributions to international commerce, could seem less open using the conventional metric.

CTS that consider global trade share, can assess economic openness in a more comprehensive way. This helps overcome the limitations of one-dimensional trade indicators and provides greater comparability across countries (Squalli and Wilson, 2011).

All data used in the calculation of CTS are from the World Bank World Development Indicators (World Bank, 2025).

5 Empirical Methodology

5.1 Main Estimation Model

We use a fixed effects panel regression model to study how a country's position in the global value chain (GVC) affects its gross national income. GVC position is the main explanatory variable, and we also control for several structural factors, such as government

effectiveness, human capital, natural resource endowment, and trade openness. The baseline regression is specified as Equation 12:

$$GNI_{it} = \beta_0 + \beta_1 GVC_{position;it} + \boldsymbol{\beta_2 Z}'_{it} + \alpha_i + \gamma_t + \varepsilon_{it} \tag{12}$$

where GNI_{it} denotes the gross national income of country i at time t, and $GVC_{position;it}$ refers to country i's overall position in the global value chain at time t. We include a 1×4 vector $\mathbf{Z}'_{it}$ of control variables in the regression, including government effectiveness GE, average years of schooling AYS, natural resource endowment NRE, and composite trade share CTS, as listed in Table 2. α_i represents time-invariant characteristics at the country level, and γ_t controls for year-specific global shocks that may affect all countries simultaneously, including macroeconomic fluctuations and international policy changes.

Equation 13 incorporates a squared term of GVC position to allow for a more flexible nonlinear relationship. By adding squared terms, we can explore whether there is a nonlinear relationship between GVC position and GNI.

$$GNI_{it} = \beta_0 + \beta_1 GVC_{position;it} + \beta_2 GVC^2_{position;it} + \boldsymbol{\beta_3 Z}'_{it} + \alpha_i + \gamma_t + \varepsilon_{it} \tag{13}$$

In Equation 14, we introduce the absolute value of GVC position, meaning the distance of a country from the middle position in the GVC. Since a GVC position close to zero typically indicates a middle-stream role, the absolute value reflects how far a country is positioned toward either the upstream or downstream end.

$$GNI_{it} = \beta_0 + \beta_1 |GVC_{position;it}| + \boldsymbol{\beta_2 Z}'_{it} + \alpha_i + \gamma_t + \varepsilon_{it} \tag{14}$$

Forward and backward GVC participation are introduced in Equation 15, capturing different dimensions of global value chain integration.

$$GNI_{it} = \beta_0 + \beta_1 GVC_{forward;it} + \beta_2 GVC_{backward;it} + \boldsymbol{\beta_3 Z}'_{it} + \alpha_i + \gamma_t + \varepsilon_{it} \tag{15}$$

In addition, Equation 16 includes an interaction term between forward and backward participation which are able to examine potential interaction effects.

$$\begin{aligned} GNI_{it} = {} & \beta_0 + \beta_1 GVC_{forward;it} + \beta_2 GVC_{backward;it} \\ & + \beta_3 \left(GVC_{forward;it} \times GVC_{backward;it} \right) + \boldsymbol{\beta_4 Z}'_{it} + \alpha_i + \gamma_t + \varepsilon_{it} \end{aligned} \tag{16}$$

To further examine the role of different sectors in impacting GNI, We decompose the country-level GVC position into three sector-specific positions: primary, secondary, and tertiary sector. The classification for economic activities by sector is shown in Table A1.

The regression model is shown as Equation 17:

$$GNI_{it} = \beta_0 + \beta_1 GVC_{primary;it} + \beta_2 GVC_{secondary;it} + \beta_3 GVC_{tertiary;it} + \boldsymbol{\beta_4}\mathbf{Z}'_{it} + \alpha_i + \gamma_t + \varepsilon_{it} \tag{17}$$

5.2 Heterogeneity Analysis

In the following heterogeneity analysis, we divide the set of 40 selected countries into two subgroups by income level according to the standard of World Bank (2023). A full list of countries is provided in Table A2. Let $\mathcal{C}$ denote the set of all countries included in the analysis. This set is partitioned into a high-income group H, and a middle-income group M, following the World Bank income classification. Mathematically, we define:

$$H \cup M = \mathcal{C}, \; H \cap M = \emptyset, \; i \in \mathcal{C} \tag{18}$$

Equation 19–24 show several model specifications with group-based variations. In each case, group-specific parameters are indexed by $g(i) \in \{h, m\}$, which denotes the group indicator for each country i. Specifically, we define $g(i) = h$ if $i \in H$, and $g(i) = m$ if $i \in M$.

$$GNI_{it} = \beta_0^{g(i)} + \beta_1^{g(i)} GVC_{position;it} + \boldsymbol{\beta_2}^{g(i)}\mathbf{Z}'_{it} + \alpha_i^{g(i)} + \gamma_t + \varepsilon_{it}^{g(i)}, \text{ for } i \in \{H, M\} \tag{19}$$

$$GNI_{it} = \beta_0^{g(i)} + \beta_1^{g(i)} GVC_{position;it} + \beta_2^{g(i)} GVC^2_{position;it} + \boldsymbol{\beta_3}^{g(i)}\mathbf{Z}'_{it} + \alpha_i^{g(i)} + \gamma_t + \varepsilon_{it}^{g(i)} \tag{20}$$

$$GNI_{it} = \beta_0^{g(i)} + \beta_1^{g(i)} |GVC_{position;it}| + \boldsymbol{\beta_2}^{g(i)}\mathbf{Z}'_{it} + \alpha_i^{g(i)} + \gamma_t + \varepsilon_{it}^{g(i)} \tag{21}$$

$$GNI_{it} = \beta_0^{g(i)} + \beta_1^{(g)} GVC_{forward;it} + \beta_2^{g(i)} GVC_{backward;it} + \boldsymbol{\beta_3}^{g(i)}\mathbf{Z}'_{it} + \alpha_i^{g(i)} + \gamma_t + \varepsilon_{it}^{g(i)} \tag{22}$$

$$\begin{aligned} GNI_{it} = {} & \beta_0^{g(i)} + \beta_1^{g(i)} GVC_{forward;it} + \beta_2^{g(i)} GVC_{backward;it} \\ & + \beta_3^{g(i)} \left(GVC_{forward;it} \times GVC_{backward;it}\right) + \boldsymbol{\beta_4}^{g(i)}\mathbf{Z}'_{it} + \alpha_i^{g(i)} + \gamma_t + \varepsilon_{it}^{g(i)} \end{aligned} \tag{23}$$

$$\begin{aligned} GNI_{it} = {} & \beta_0^{g(i)} + \beta_1^{g(i)} GVC_{primary;it} + \beta_2^{g(i)} GVC_{secondary;it} + \beta_3^{g(i)} GVC_{tertiary;it} \\ & + \boldsymbol{\beta_4}^{g(i)}\mathbf{Z}'_{it} + \alpha_i^{g(i)} + \gamma_t + \varepsilon_{it}^{g(i)} \end{aligned} \tag{24}$$

5.3 Model Diagnostics

In order to check whether the basic assumptions of the fixed effects model hold, a series of specification and robustness tests are conducted across all twelve model specifications (Wooldridge, 2010). The Hausman test is employed to assess the appropriateness of the fixed effects estimator (Hausman, 1978). We also conduct tests for heteroskedasticity and

serial correlation to evaluate the structure of the error terms. In addition, we use a cross-sectional dependence test to identify potential inter-country dependencies. Endogeneity tests are also carried out to confirm that the main explanatory variables are uncorrelated with the error term. Detailed results are provided in the Appendix.

To examine whether the fixed effects model is appropriate, we carry out Hausman tests for all twelve model specifications. The results in Table A3 consistently support the fixed effects estimator, indicating that unobserved country-specific effects are correlated with the explanatory variables. The test results are very significant, with p-values far below the 1% level in every model, which strongly confirms the validity of using the fixed effects approach in this study.

We use Breusch-Pagan tests to check whether heteroskedasticity problem exists in our models (Breusch and Pagan, 1979). According to the results in Table A4, all models show strong signs of heteroskedasticity, with highly significant statistics and p-values much smaller than 0.01. This outcome suggests that there are heteroskedasticity problems in our models, and it justifies the application of heteroskedasticity-robust standard errors in estimation.

To examine the presence of serial correlation in the fixed effects panel models, we conduct the Breusch–Godfrey test with a lag order of 5 (Breusch, 1978). We set the lag order to 5 test to ensure sufficient sensitivity in detecting higher-order serial correlation. As Table A5, all models yield highly significant results at the 1% level, suggesting strong evidence of serial correlation. The alternative hypothesis of this test states that the idiosyncratic error term ε_{it} is autocorrelated for at least one lag up to the specified order. These findings indicate a violation of the classical assumption of error independence. In this case, country-clustered standard errors can handle the problems of heteroskedasticity and serial correlation.

Colin Cameron and Miller (2015) indicate that the validity of standard errors clustered ar country level is baesd on on the assumption of cross-sectional independence, which ,however, may not always hold. We conduct the Breusch–Pagan LM test for each model to test if there is correlation across countries. The results, as shown in Table A6, indicate that we strongly reject the null hypothesis of cross-sectional independence in all cases. The result shows that many countries are not independent from each other. This kind of cross-sectional dependence may come from shared shocks, regional integration, or global trends. Therefore, we apply Driscoll–Kraay standard errors, which are robust not only to heteroskedasticity, serial correlation, but also to more general types of spatial dependence (Driscoll and Kraay, 1998).

6 Result and Analysis

The regression results of this paper are divided into three parts. The first part is the results about the GVC position. As shown in Table 3, the nine columns are divided into three groups: full sample, high income group and middle income group. All all employ fixed effect models, such as year-fixed effects and country-fixed effects. The following results tables will be shown in the same format.

The explanatory variables of all models are lagged by one period, reflecting the process of GVC changes being transmitted to GNI, while weakening the impact of endogeneity problems. Among the control variables, government effectiveness (GE), average years of schooling (AYS), and composite trade share (CTS) are lagged by two periods to avoid the problem of two-way influence on GNI. However, NRE is special. We choose to use the maximum lag order allowed by the data, that is, 5 periods. Collier and Goderis (2012) found that the impact of non-agricultural rents on economic growth depends on the quality of national governance. Collier's definition of exclusion of agriculture is consistent with the definition of natural resources in this paper (see Section 4.1). Non-agricultural rents have a significant negative impact on long-term economic growth in countries with poor governance, while the impact may be positive in countries with good governance. The case of Norway is used to confirm this conclusion: in 1990, non-agricultural exports accounted for 15% of its GDP. The model predicts that a 10% increase in non-agricultural prices will lead to a long-term increase in per capita GDP of 2.1% to 3.5%. Therefore, this study sets the lag order of natural resource rent (as a percentage of GDP) to 5 years to identify the medium- and long-term impact path of natural resource rent on GNI and avoid the interference of resource fluctuations on the short-term GVC position and income linkage as much as possible.

6.1 Result of Global Value Chain Position Regression

Table 3. Fixed Effects Regression of the Effect of GVC Position on GNI by Income-Level Group

	Full sample			High income			Middle income		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
$GVC_{position}$	15.986***	1.079		39.276***	3.977		9.170***	11.648***	
	(1.999)	(4.996)		(6.829)	(17.029)		(1.329)	(3.048)	
$GVC^2_{position}$		41.522***			82.531**			−8.013	
		(11.589)			(38.361)			(9.358)	
$\lvert GVC_{position}\rvert$			13.979***			39.957***			7.773***
			(2.216)			(7.169)			(1.430)
GE	2.000***	1.827***	1.929***	3.198***	3.239***	3.198***	2.363**	2.449*	2.318*
	(0.752)	(0.692)	(0.739)	(0.771)	(0.752)	(0.763)	(1.190)	(1.266)	(1.233)
AYS	−1.028***	−1.150***	−1.170***	−0.973***	−1.125***	−0.996***	0.035	0.054	−0.050
	(0.201)	(0.203)	(0.204)	(0.230)	(0.173)	(0.236)	(0.100)	(0.112)	(0.101)
NRE	0.150*	0.153**	0.174**	0.345***	0.313***	0.343***	0.056	0.054	0.075
	(0.077)	(0.076)	(0.075)	(0.127)	(0.114)	(0.128)	(0.115)	(0.114)	(0.115)
CTS	0.708***	0.654***	0.643***	1.499***	1.301***	1.498***	0.496***	0.504***	0.446***
	(0.121)	(0.102)	(0.091)	(0.182)	(0.199)	(0.184)	(0.058)	(0.062)	(0.050)
Country fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	800	800	800	400	400	400	400	400	400
R^2	0.1530	0.1712	0.1422	0.3383	0.3719	0.3400	0.1812	0.1828	0.1700
Adjusted R^2	0.0805	0.0990	0.0688	0.2584	0.2941	0.2603	0.0823	0.0815	0.0698

Note. Driscoll-Kraay standard errors, which are robust to heteroskedasticity, autocorrelation, and cross-sectional dependence, are reported in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Column (1), (4), and (7) in the table are regression models with GVC position as the independent variable, corresponding to Equation 12 and Equation 19. GVC position is statistically significant in all three models, all below the 1% level. In the whole sample, when GVC position rises by one unit (thousand 2021 International US dollar, PPP), GNI rises by nearly 16 units on average. In the high-income group, GNI rises by an average of 39.276 units, while in the middle-income group, the average increase is only 9.17 units.

Column (2), (5), and (8) correspond to Equation 13 and Equation 20, studying the nonlinear relationship between GVC position and GNI.

Columns (3), (6), and (9), which correspond to Equation 14 and Equation 21, examine the relationship between the distance from the middle of the GVC and GNI. We found that the results of the three groups are all significant at the 1% level. The effect of the high-income group is the most obvious, reaching 39.957 units, while the middle-income group only has an increase of 7.773 units.

6.2 Result of Global Value Chain Participation Regression

Table 4. Fixed Effects Regression of the Effect of GVC Participation on GNI by Income-Level Group

	Full sample		High income		Middle income	
	(10)	(11)	(12)	(13)	(14)	(15)
$GVC_{forward}$	11.806***	22.576***	12.791*	37.017***	−4.087	−4.318
	(3.831)	(4.091)	(7.124)	(10.381)	(3.034)	(5.716)
$GVC_{backward}$	−11.529***	17.211*	−45.559***	23.274	−18.843***	−19.387**
	(3.236)	(9.440)	(9.840)	(34.918)	(2.929)	(9.797)
$GVC_{forward} \times GVC_{backward}$		−76.467***		−161.342*		1.552
		(22.051)		(94.069)		(23.456)
GE	1.970***	1.908***	3.253***	3.409***	2.525**	2.530**
	(0.749)	(0.709)	(0.807)	(0.806)	(1.199)	(1.257)
AYS	−1.047***	−1.146***	−0.968***	−1.100***	−0.000	0.002
	(0.187)	(0.184)	(0.209)	(0.151)	(0.082)	(0.109)
NRE	0.147*	0.165**	0.366***	0.368***	0.073	0.072
	(0.078)	(0.083)	(0.135)	(0.120)	(0.118)	(0.118)
CTS	0.711***	0.680***	1.566***	1.446***	0.534***	0.534***
	(0.124)	(0.111)	(0.204)	(0.221)	(0.054)	(0.054)
Country fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
N	800	800	400	400	400	400
R^2	0.1534	0.1638	0.3390	0.3632	0.2026	0.2026
Adjusted R^2	0.0797	0.0898	0.2571	0.2822	0.1037	0.1012

Note. Driscoll-Kraay standard errors, which are robust to heteroskedasticity, autocorrelation, and cross-sectional dependence, are reported in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table 4 shows the impact of GVC forward and backward participation, as well as their interaction terms, on GNI. Columns (10), (12), and (14) do not add the forward-backward interaction term, corresponding to Equation 15 and Equation 22.

In the full sample (column 10) and high-income group (column 12), forward participation has a significant positive impact on GNI, with coefficients of 11.806 ($p < 0.01$) and 12.791 ($p < 0.1$), respectively. Backward participation, on the other hand, has a negative impact, with coefficients of −11.529 ($p < 0.01$) and -45.559 ($p < 0.01$), respectively. In the middle-income group (column 14), the coefficient of forward participation is −4.087, and the coefficient of backward participation is −18.843 ($p < 0.01$), indicating that in middle-income countries, forward and backward participation has not yet formed a stable positive effect, although the negative impact of backward participation is significant, while forward participation is not significant.

Column (11), (13), and (15) correspond to Equation 16 and Equation 23, and interaction terms are added to analyze the nonlinear linkage effect of deep embedding.

In the full sample (column 11), the coefficient of forward participation is 22.576 ($p < 0.01$), and the coefficient of backward participation is 17.211 ($p < 0.1$), but the interaction term is -76.467 ($p < 0.01$), which is significantly negative, indicating that there is a phenomenon of diminishing marginal returns or increasing coordination costs in bidirectional embedding. In the high-income group (column 13), the coefficients of forward participation and backward participation are 37.017 ($p < 0.01$) and 23.274 (not significant), respectively, but the interaction term is still -161.342 ($p < 0.1$), further supporting the interpretation that there is a negative compound effect of two-way embeddedness. In the middle-income group (column 15), the coefficients of all variables are not significant: forward participation -4.318, backward participation -19.387 ($p < 0.05$), and the interaction term 1.552 (not significant), indicating that middle-income countries have failed to gain growth momentum from two-way embeddedness, and even show a negative effect. Backward participation has the strongest negative impact on GNI in all groups, especially in the high-income group (-45.559, $p < 0.01$) and the middle-income group (-19.387, $p < 0.05$), suggesting that it may represent processing trade or low value-added lock-in effect. Although the interaction term is positive in the middle-income group, it is not significant (1.552), indicating that bidirectional embedding does not show a compound positive effect or marginal benefit recovery.

6.3 Result of Sectoral Global Value Chain Position Regression

Table 5. Fixed Effects Regression of the Effect of Sectoral GVC Position on GNI by Income-Level Group

	Full sample (16)	High income (17)	Middle income (18)
$GVC_{primary}$	13.673	8.570	−1.368
	(31.353)	(112.389)	(20.884)
$GVC_{secondary}$	12.323*	48.768***	16.597***
	(6.638)	(9.225)	(4.963)
$GVC_{tertiary}$	−7.731	11.620	−0.711
	(5.306)	(11.797)	(4.872)
GE	2.295***	3.174***	2.562**
	(0.752)	(0.785)	(1.176)
AYS	−1.179***	−1.087***	0.017
	(0.201)	(0.170)	(0.129)
NRE	0.172**	0.532***	0.056
	(0.077)	(0.174)	(0.110)
CTS	0.549***	1.242***	0.427***
	(0.121)	(0.194)	(0.056)
Country fixed effects	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes
N	800	400	400
R^2	0.1240	0.2796	0.1890
Adjusted R^2	0.0464	0.1880	0.0859

Note. Driscoll-Kraay standard errors, which are robust to heteroskedasticity, autocorrelation, and cross-sectional dependence, are reported in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table 5 shows the extent to which the GVC position of the three sectors affects GNI. In the three groups, for every 1 unit increase in the GVC position of the secondary industry, GNI increases by 12.323 units, 48.786 units, and 16.597 units on average, respectively, and all are statistically significant. The impact of the secondary industry is most significant in the high-income group. However, the primary and tertiary industries are statistically insignificant in all three groups, so we cannot reject the hypothesis that there is no impact on GNI.

6.4 Robustness Test

In Section 4.1, we mention that this paper uses a total of 20 years of data, of which the first three years are discontinuous. Therefore, we choose to conduct a regression with 17 consecutive years of data as a robustness test and compare it with the results of Section 6.

Table 6, Table 7, and Table 8 correspond to the previous tables in order and have the same structure.

Table 6. Robustness Test of the Effect of GVC Position on GNI

	Full sample			High income			Middle income		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
$GVC_{position}$	17.048***	9.495		34.651***	21.770**		9.187***	9.508**	
	(3.339)	(6.051)		(7.048)	(9.064)		(2.504)	(4.631)	
$GVC^2_{position}$		19.651**			30.389*			−0.904	
		(9.889)			(17.138)			(7.122)	
$\|GVC_{position}\|$			15.285***			35.054***			7.223***
			(2.763)			(7.173)			(1.794)
GE	1.368**	1.369**	1.368**	2.191***	2.324***	2.208***	2.424***	2.429***	2.469***
	(0.674)	(0.651)	(0.681)	(0.681)	(0.757)	(0.683)	(0.900)	(0.928)	(0.926)
AYS	−0.881***	−0.923***	−0.974***	−1.088***	−1.160***	−1.118***	−0.013	−0.011	−0.094
	(0.160)	(0.188)	(0.173)	(0.188)	(0.206)	(0.195)	(0.099)	(0.115)	(0.094)
NRE	0.047	0.050	0.070*	0.300***	0.298***	0.300***	−0.122**	−0.122**	−0.106**
	(0.052)	(0.051)	(0.041)	(0.074)	(0.074)	(0.075)	(0.052)	(0.054)	(0.048)
CTS	0.937***	0.886***	0.823***	1.524***	1.432***	1.517***	0.600***	0.602***	0.491***
	(0.084)	(0.078)	(0.086)	(0.222)	(0.192)	(0.221)	(0.079)	(0.086)	(0.064)
Country fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	680	680	680	340	340	340	340	340	340
R^2	0.1628	0.1675	0.1529	0.3272	0.3325	0.3272	0.2458	0.2458	0.2332
Adjusted R^2	0.0816	0.0853	0.0708	0.2372	0.2407	0.2372	0.1449	0.1420	0.1306

Note. Driscoll-Kraay standard errors, which are robust to heteroskedasticity, autocorrelation, and cross-sectional dependence, are reported in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table 6 corresponds to Table 3 in Section 6. We found that the estimated coefficients of the independent variables of each model are consistent with the main regression results in terms of sign direction and significance level. This shows that the main regression results do not depend on the sample structure of discontinuous years and have good time robustness.

However, compared with the main regression results Table 3, Column (5) in Table 6 shows that the coefficients of $GVC_{position}$ and $GVC^2_{position}$ are both statistically significant, while $GVC_{position}$ is not significant in the main regression. This shows that under the robust subsample, the nonlinear relationship (positive U-shaped relationship) between GVC and GNI is clearer and the regression results are more robust.

Table 7. Robustness Test of the Effect of GVC Participation on GNI

	Full sample		High income		Middle income	
	(10)	(11)	(12)	(13)	(14)	(15)
$GVC_{forward}$	10.046***	15.909***	17.884***	25.315***	−1.315	1.188
	(3.210)	(2.988)	(5.878)	(5.523)	(1.730)	(2.520)
$GVC_{backward}$	−15.848***	0.387	−33.637***	−12.947	−15.832***	−9.263
	(1.911)	(10.388)	(11.559)	(14.385)	(2.562)	(9.109)
$GVC_{forward} \times GVC_{backward}$		−41.675*		−47.978		−17.806
		(24.135)		(39.995)		(21.896)
GE	1.345**	1.354**	2.172***	2.294***	2.444***	2.406***
	(0.669)	(0.644)	(0.692)	(0.760)	(0.899)	(0.906)
AYS	−0.884***	−0.960***	−1.080***	−1.124***	−0.130	−0.173
	(0.161)	(0.204)	(0.190)	(0.209)	(0.108)	(0.152)
NRE	0.047	0.056	0.307***	0.313***	−0.113**	−0.108*
	(0.054)	(0.055)	(0.082)	(0.083)	(0.054)	(0.058)
CTS	0.953***	0.915***	1.547***	1.493***	0.622***	0.604***
	(0.087)	(0.082)	(0.254)	(0.229)	(0.093)	(0.089)
Country fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
N	680	680	340	340	340	340
R^2	0.1658	0.1696	0.3279	0.3305	0.2604	0.2620
Adjusted R^2	0.0835	0.0861	0.2354	0.2359	0.1587	0.1576

Note. Driscoll-Kraay standard errors, which are robust to heteroskedasticity, autocorrelation, and cross-sectional dependence, are reported in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Compared with Table 4, the robustness test results in Table 7 show that the impact of GVC forward and backward participation on GNI in the full sample and high-income group is generally consistent, supporting the robustness of the main regression conclusion. The coefficient of GVC forward participation is still positive and statistically significant in the full sample and high-income group, indicating that improving the forward participation of GVC will help improve the national income level. The estimated results of GVC backward show some differences. In the main regression, it shows a significant negative impact on the full sample and the middle-income group, and it remains consistent in the direction in the robust regression. For the interaction terms, although many groups are significant in the main regression, most of them are not significant in the robustness test, but the direction is consistent and negative, indicating that there may be diminishing marginal returns or conflicts in participation efficiency between forward and backward participation.

Table 8. Robustness Test of the Effect of Sectoral GVC Position on GNI

	Full sample (16)	High income (17)	Middle income (18)
$GVC_{primary}$	-69.984^{***}	-137.406	-62.116^{***}
	(11.055)	(103.841)	(4.349)
$GVC_{secondary}$	19.360^{**}	47.693^{***}	8.158
	(9.699)	(11.583)	(6.929)
$GVC_{tertiary}$	-8.774	16.380	10.559^{**}
	(7.066)	(11.337)	(5.182)
GE	1.607^{**}	2.229^{**}	2.568^{**}
	(0.752)	(0.884)	(0.854)
AYS	-0.697^{***}	-1.081^{***}	0.139
	(0.154)	(0.170)	(0.109)
NRE	0.070	0.401^{***}	-0.104^{**}
	(0.054)	(0.100)	(0.050)
CTS	0.692^{***}	1.331^{***}	0.431^{***}
	(0.095)	(0.185)	(0.075)
Country fixed effects	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes
N	680	340	340
R^2	0.1639	0.3005	0.3053
Adjusted R^2	0.0799	0.2015	0.2070

Note. Driscoll-Kraay standard errors, which are robust to heteroskedasticity, autocorrelation, and cross-sectional dependence, are reported in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table 8 shows the results of robustness tests on the GVC position of different sectors. Compared with Table5, the GVC position of the secondary industry still maintains a statistically significant positive impact, especially in the high-income group. However, the results of the primary and tertiary industries differ from the main regression in terms of effect direction and statistical significance. Therefore, we find that both the main regression and the robustness test emphasize the importance of the improvement of the GVC position of the secondary industry on GNI growth.

7 Discussion and Conclusion

High-income countries benefit more from the rise in GVC, and middle-income countries also benefit from it, but the effect is smaller. This comparison of results shows that the ability of high-income and middle-income countries to benefit from GVC upgrading is heterogeneous, which may depend on the country's structural and institutional capabilities.

Further analysis shows that there is a significant nonlinear relationship between GVC and GNI in the full sample and high-income group. The results of column (2) and (5) show the squared term is significantly positive, and the extreme points x_2^* and x_5^* are $x_2^* = -\frac{\beta_1}{2\beta_2} \approx -0.013$ and $x_5^* = -\frac{\beta_1^h}{2\beta_2^h} \approx -0.024$, respectively, both of which are within the theoretical value range of $GVC_{position;it} \in [-\ln 2, \ln 2]$, indicating that GVC may present a positive U-shaped structure to GNI in the full sample and high-income group. Although the coefficient of the linear term is not significant, the extreme point is very close to the sample center, which still supports the validity of the nonlinear explanation. In addition, Columns (3), (6), and (9) indicate that the farther away from the middle, the higher the GNI value.

The above results show that the relationship between GVC position and GNI presents a positive U-shaped structure, which is consistent with the theory proposed in Section 3 and is consistent with the empirical results of Timmer et al. (2014).

In terms of GVC participation, forward participation has a significant positive impact on GNI, while backward participation has a negative impact on GNI in the full sample and high-income group. For the middle-income group, forward and backward participation have not yet formed a stable positive effect, even though forward participation is not statistically significant.

Columns (11), (13), and (15), corresponding to Equation 16 and Equation 23, introduce the interaction terms. In the full sample and high-income group, both forward and backward participation have a separate positive effect on GNI, although backward participation is not statistically significant in the high-income group. However, the interaction term shows that in the full sample and high-income group, the deep embedding of forward and backward participation may lead to diminishing marginal benefits or rising complex coordination costs. In the middle-income group, the results show no significant impact on GNI, or even negative, indicating that middle-income countries have failed to gain growth momentum from forward embedding. At the same time, the impact of backward participation on GNI is significantly negative, indicating that backward embedding has a suppressive effect on economic growth, which may be passive processing and low added value lock-in. Although the interaction term is positive, it is not significant, indicating that two-way deep embedding does not show compounding effect or marginal return reversal. Overall, forward embedding has a stronger positive effect on economic growth, while the impact of backward embedding is weaker or even negative, and there is a diminishing marginal return effect in two-way deep embedding.

We also find importance of industrial structure from the regression of GVC position on GNI at the sector level. In the whole sample, high-income group and middle-income group, the GVC upgrade of the secondary industry has a significant impact on the improvement of GNI. This conclusion is consistent with previous studies. One of the core views of Timmer et al. (2014) is that the improvement of a country's manufacturing

position in the global value chain has a significant positive impact on its national income growth. Economies with higher forward participation tend to retain more domestic value added, thereby driving the increase in GNI. Taglioni and Winkler (2016) also proposed that in order to achieve economic development through the global value chain, it must be accompanied by industrial upgrading, especially in the manufacturing sector, which is one of the important areas of industry. Simply participating in the global production chain (increasing GVC participation) is not enough to bring development benefits. The key is whether a country has the ability to move up to more complex manufacturing stages, which are often associated with higher productivity and income levels. This process is particularly important for middle-income countries that want to escape the low value-added trap.

Although this study uses GNI denominated in international dollars after PPP adjustment to enhance cross-national comparability, this indicator is still too vague to measure the actual living standards of citizens. Development differences within different countries (such as cross-country spatial spikiness in China, the United States, Japan, etc.), as well as differences in the distribution of fixed expenditure (such as taxes, insurance premiums, rent or mortgages, transportation costs, water, electricity, gas, etc.) and flexible consumption (such as food expenses, electronic product expenses, daily necessities and entertainment consumption) in different regions make it difficult for GNI to fully reflect the quality of life of residents. Future research can be further developed from the perspective of region and industry, for example, to explore whether the development of high value-added industrial clusters can improve the actual living standards of residents in a specific region. However, related research faces challenges in data acquisition and measurement dimensions, which deserves further exploration.

Reference

Acemoglu, D., Johnson, S.H. and Robinson, J.A. (2001). The Colonial Origins of Comparative Development: an Empirical Investigation. *American Economic Review*, 91(5), pp.1369–1401.

Antràs, P. and Chor, D. (2022). Global Value Chains. *Handbook of International Economics: International Trade, Volume 5*, [online] 5, pp.297–376. doi:https://doi.org/10.1016/bs.hesint.2022.02.005.

Baldwin, R. (2016). *The great convergence : Information technology and the new globalization*. Cambridge, Massachusetts: The Belknap Press Of Harvard University Press.

Breusch, T.S. (1978). Testing for Autocorrelation in Dynamic Linear Models. *Australian Economic Papers*, 17(31), pp.334–355. doi:https://doi.org/10.1111/j.1467-8454.1978.tb00635.x.

Breusch, T.S. and Pagan, A.R. (1979). A Simple Test for Heteroscedasticity and Random Coefficient Variation. *Econometrica*, 47(5), pp.1287–1294. doi:https://doi.org/10.2307/1911963.

Colin Cameron, A. and Miller, D.L. (2015). A Practitioner's Guide to Cluster-Robust Inference. *Journal of Human Resources*, 50(2), pp.317–372. doi:https://doi.org/10.3368/jhr.50.2.317.

Collier, P. and Goderis, B. (2012). Commodity prices and growth: An empirical investigation. *European Economic Review*, 56(6), pp.1241–1260. doi:https://doi.org/10.1016/j.euroecorev.2012.04.002.

Corden, W.M. and Neary, J.P. (1982). Booming Sector and DeIndustrialisation in a Small Open Economy. *The Economic Journal*, 92(368), pp.825–848.

De Marchi, V. and Alford, M. (2021). State policies and upgrading in global value chains: A systematic literature review. *Journal of International Business Policy*, 5. doi:https://doi.org/10.1057/s42214-021-00107-8.

Ding, X. (2008). Research on Modularity Governance Pattern of the Global Value Chains Theory. *Dianzi Ke-Ji Daxue xuebao. She-ke ban.*

Driscoll, J.C. and Kraay, A.C. (1998). Consistent Covariance Matrix Estimation with Spatially Dependent Panel Data. *Review of Economics and Statistics*, 80(4), pp.549–560. doi:https://doi.org/10.1162/003465398557825.

Gereffi, G., Humphrey, J. and Sturgeon, T. (2005). The Governance of Global Value Chains. *Review of International Political Economy*, [online] 12(1), pp.78–104. doi:https://doi.org/10.1080/09692290500049805.

Gereffi, G. and Fernandez-Stark, K. (2016). *Global Value Chain Analysis: A Primer*. 2nd edn. Durham, NC: Duke University Press. Available at: https://hdl.handle.net/10161/12488 (Accessed: May 2025).

Gereffi, G. (1994). The organization of buyer-driven global commodity chains: How U.S. retailers shape overseas production networks. In: Gereffi, G. and Korzeniewicz, M., eds. *Commodity Chains and Global Capitalism*. Westport, CT: Praeger, pp.95–122.

Hanushek, E.A. and Woessmann, L. (2008). The Role of Cognitive Skills in Economic Development. *Journal of Economic Literature*, 46(3), pp.607–668.

Hausman, J.A. (1978). Specification Tests in Econometrics. *Econometrica*, [online] 46(6), pp.1251–1271. doi:https://doi.org/10.2307/1913827.

Hummels, D., Ishii, J. and Yi, K.-M. (2001). The nature and growth of vertical specialization in world trade. *Journal of International Economics*, 54(1), pp.75–96. doi:https://doi.org/10.1016/s0022-1996(00)00093-3.

Humphrey, J. and Schmitz, H. (2002). How does insertion in global value chains affect upgrading in industrial clusters? *Regional Studies*, [online] 36(9), pp.1017–1027. doi:https://doi.org/10.1080/0034340022000022198.

Kaplinsky, R. (2000). Globalisation and Unequalisation: What Can Be Learned from Value Chain Analysis? *Journal of Development Studies*, 37(2), pp.117–146.

Kaufmann, D., Kraay, A. and Mastruzzi, M. (2010). Response to 'What do the Worldwide Governance Indicators Measure?'. *The European Journal of Development Research*, 22(1), pp.55–58. doi:https://doi.org/10.1057/ejdr.2009.49.

Koopman, R., Powers, W., Wang, Z. and Wei, S.-J. (2010). Give Credit Where Credit Is Due: Tracing Value Added in Global Production Chains. doi:https://doi.org/10.

3386/w16426.

Mahutga, M.C. (2011). When do value chains go global? A theory of the spatialization of global value chains. *Global Networks*, 12(1), pp.1–21. doi:https://doi.org/10.1111/j.1471-0374.2011.00322.x.

Mudambi, R. (2008). Location, control and innovation in knowledge-intensive industries. *Journal of Economic Geography*, 8(5), pp.699–725. doi:https://doi.org/10.1093/jeg/lbn024.

OECD. (2017). *OECD skills outlook 2017 : skills and global value chains*. Paris: OECD, Cop.

OECD. (2025). *Trade in Value Added (TiVA) 2023 edition: Principal Indicators, levels [cloud replica]*. Available at: https://data-explorer.oecd.org/vis?pg=0&bp=true&snb=14&tm=TIVA&df[ds]=dsDisseminateFinalCloud&df[id]=DSD_TIVA_MAINLV%40DF_MAINLV&df[ag]=OECD.STI.PIE&df[vs]=1.0&dq=.....A&pd=%2C&to[TIME_PERIOD]=false&isAvailabilityDisabled=false (Accessed: May 2025).

Pipkin, S. and Fuentes, A. (2017). Spurred to Upgrade: A Review of Triggers and Consequences of Industrial Upgrading in the Global Value Chain Literature. *World Development*, [online] 98, pp.536–554. doi:https://doi.org/10.1016/j.worlddev.2017.05.009.

Raei, F., Ignatenko, A. and Mircheva, B. (2019). Global Value Chains: What are the Benefits and Why Do Countries Participate?. *IMF Working Papers*, 19(18), p.1. doi:https://doi.org/10.5089/9781484392928.001.

Rodrik, D. (2018). *Straight Talk on Trade : Ideas for a Sane World Economy*. Princeton, New Jersey: Princeton University Press.

Ross, M.L. (2015). What Have We Learned about the Resource Curse? *Annual Review of Political Science*, 18(1), pp.239–259. doi:https://doi.org/10.1146/annurev-polisci-052213-040359.

Sachs, J. and Warner, A. (1995). *Natural Resource Abundance and Economic Growth*. doi:https://doi.org/10.3386/w5398.

Squalli, J. and Wilson, K. (2011). A New Measure of Trade Openness. *The World*

Economy, 34(10), pp.1745–1770. doi:https://doi.org/10.1111/j.1467-9701.2011.01404.x.

Taglioni, D. and Winkler, D. (2016). *Making Global Value Chains Work for Development*. [online] Washington, DC: World Bank. doi:https://doi.org/10.1596/978-1-4648-0157-0.

Timmer, M.P., Erumban, A.A., Los, B., Stehrer, R. and de Vries, G.J. (2014). Slicing up Global Value Chains. *Journal of Economic Perspectives*, 28(2), pp.99–118. doi:https://doi.org/10.1257/jep.28.2.99.

UNCTAD. (2021). *Digital Economy Report 2021: Cross-border Data Flows and Development*. Geneva: United Nations Conference on Trade and Development. Available at: https://unctad.org/publication/digital-economy-report-2021 (Accessed: May 2025).

UNDP. (2025). *Average years of schooling*. Available at: https://hdr.undp.org/data-center/documentation-and-downloads (Accessed: May 2025).

UNDP. (2024). *Human Development Report 2023/2024*. Stylus Publishing, LLC.

United Nations (New York). Department Of Economic And Social Affairs. Statistics Division (2008). *International standard industrial classification of all economic activities (ISIC)*. New York: United Nations.

Wooldridge, J.M. (2010). *Econometric analysis of cross section and panel data. [2] Student's solutions manual and supplementary materials for Econometric analysis of cross section and panel data*. Cambridge, Mass. Mit Press.

World Bank. (2025). *Exports of goods and services (current US$)*. Available at: https://data.worldbank.org/indicator/NE.EXP.GNFS.CD (Accessed: May 2025).

World Bank. (2025). *Imports of goods and services (current US$)*. Available at: https://data.worldbank.org/indicator/NE.IMP.GNFS.CD (Accessed: May 2025).

World Bank. (2025). *GDP (current US$)*. Available at: https://data.worldbank.org/indicator/NY.GDP.MKTP.CD (Accessed: May 2025).

World Bank. (2025). *GNI per capita, PPP (constant 2021 international $)*. Available at: https://data.worldbank.org/indicator/NY.GNP.PCAP.PP.KD (Accessed: May 2025).

World Bank. (2025). *Government Effectiveness: Estimate*. Available at: https://databank.worldbank.org/metadataglossary/worldwide-governance-indicators/series/GE.EST (Accessed: May 2025).

World Bank. (2025). *Total natural resources rents (% of GDP)*. Available at: https://databank.worldbank.org/metadataglossary/adjusted-net-savings/series/NY.GDP.TOTL.RT.ZS (Accessed: May 2025).

World Bank. (2023). *World Bank Country and Lending Groups – World Bank Data Help Desk*. [online] Worldbank.org. Available at: https://datahelpdesk.worldbank.org/knowledgebase/articles/906519.

Appendix

Figure A1. Geographic Distribution of Sample Countries by Income Group

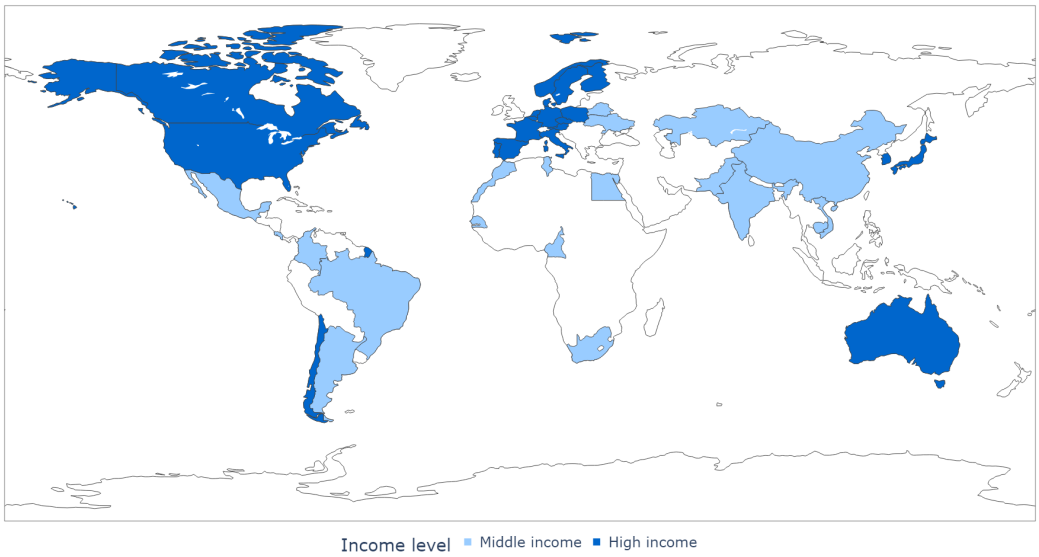

Table A1. Economic Activities Classified by ISIC Rev.4

	TiVA Code		TiVA Code		TiVA Code
Primary sector		Manufacture of basic metals	C24	Warehousing and support activities for transportation	H52
Agriculture and forestry	A01_02	Manufacture of fabricated metal products, except machinery and equipment	C25	Postal and courier activities	H53
Fishing and aquaculture	A03	Manufacture of computer, electronic and optical products	C26	Accommodation and food service activities	I
Mining and extraction of energy producing products	B05_06	Manufacture of electrical equipment	C27	Publishing, motion picture, video, television programme production; sound recording, programming and broadcasting activities	J58T60
Mining and quarrying of non-energy producing products	B07_08	Manufacture of machinery and equipment n.e.c.	C28	Telecommunications	J61
Mining support service activities	B09	Manufacture of motor vehicles, trailers and semi-trailers	C29	Computer programming, consultancy, and information service activities	J62_63
Secondary sector		Manufacture of other transport equipment	C30	Financial and insurance activities	K
Manufacture of food products; beverages and tobacco products	C10T12	Manufacture of furniture; jewellery, musical instruments, toys, etc.; repair and installation of machinery and equipment	C31T33	Real estate activities	L
Manufacture of textiles, wearing apparel, leather and related products	C13T15	Electricity, gas, steam and air conditioning supply	D	Professional, scientific and technical activities	M
Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials	C16	Water supply; sewerage, waste management and remediation activities	E	Administrative and support service activities	N
Manufacture of paper and paper products; printing and reproduction of recorded media	C17_18	Construction	F	Public administration and defence; compulsory social security	O
Manufacture of coke and refined petroleum products	C19	*Tertiary sector*		Education	P
Manufacture of chemicals and chemical products	C20	Wholesale and retail trade; repair of motor vehicles and motorcycles	G	Human health and social work activities	Q
Manufacture of basic pharmaceutical products and pharmaceutical preparations	C21	Land transport and transport via pipelines	H49	Arts, entertainment and recreation	R
Manufacture of rubber and plastics products	C22	Water transport	H50	Other service activities	S
Manufacture of other non-metallic mineral products	C23	Air transport	H51	Activities of households as employers; undifferentiated goods- and services-producing activities of households for own use	T

Source. United Nations (2008)

Table A2. List of Countreis Grouped by Income Level

Country Code		Country Code	
High income		*Middle income*	
Australia	AUS	Argentina	ARG
Austria	AUT	Belarus	BLR
Belgium	BEL	Brazil	BRA
Canada	CAN	China	CHN
Chile	CHL	Cameroon	CMR
Czechia	CZE	Colombia	COL
Germany	DEU	Costa Rica	CRI
Denmark	DNK	Egypt, Arab Rep.	EGY
Spain	ESP	India	IND
Finland	FIN	Kazakhstan	KAZ
France	FRA	Cambodia	KHM
Italy	ITA	Morocco	MAR
Japan	JPN	Mexico	MEX
Korea, Rep.	KOR	Pakistan	PAK
Netherlands	NLD	Philippines	PHL
Norway	NOR	Senegal	SEN
Poland	POL	Tunisia	TUN
Portugal	PRT	Ukraine	UKR
Sweden	SWE	Viet Nam	VNM
United States	USA	South Africa	ZAF

Source: World Bank (2023)

Note. China refers exclusively to the mainland area and does not include Hong Kong SAR, China, Macao SAR, China, and Taiwan, China.

Table A3. Hausman Tests for Model Specification

	χ^2 statistic	*df*	*p*-value	Model Selection
(1)	489.19	5	$< 2.2 \times 10^{-16}$	FE
(2)	498.88	6	$< 2.2 \times 10^{-16}$	FE
(3)	483.32	5	$< 2.2 \times 10^{-16}$	FE
(4)	404.77	5	$< 2.2 \times 10^{-16}$	FE
(5)	405.62	6	$< 2.2 \times 10^{-16}$	FE
(6)	408.03	5	$< 2.2 \times 10^{-16}$	FE
(7)	70.915	5	6.609×10^{-14}	FE
(8)	68.435	6	8.559×10^{-13}	FE
(9)	88.993	5	$< 2.2 \times 10^{-16}$	FE
(10)	352.85	6	$< 2.2 \times 10^{-16}$	FE
(11)	373.53	7	$< 2.2 \times 10^{-16}$	FE
(12)	238.14	6	$< 2.2 \times 10^{-16}$	FE
(13)	251.34	7	$< 2.2 \times 10^{-16}$	FE
(14)	114.81	6	$< 2.2 \times 10^{-16}$	FE
(15)	97.482	7	$< 2.2 \times 10^{-16}$	FE
(16)	323.93	7	$< 2.2 \times 10^{-16}$	FE
(17)	239.84	7	$< 2.2 \times 10^{-16}$	FE
(18)	102	7	$< 2.2 \times 10^{-16}$	FE

Table A4. Breusch-Pagan Tests for Heteroskedasticity

	BP statistic	*df*	*p*-value	Heteroskedasticity
(1)	68.225	5	2.398×10^{-13}	Yes
(2)	102.29	6	$< 2.2 \times 10^{-16}$	Yes
(3)	74.007	5	1.499×10^{-14}	Yes
(4)	161.32	5	$< 2.2 \times 10^{-16}$	Yes
(5)	127.07	6	$< 2.2 \times 10^{-16}$	Yes
(6)	161.3	5	$< 2.2 \times 10^{-16}$	Yes
(7)	115.94	5	$< 2.2 \times 10^{-16}$	Yes
(8)	115.31	6	$< 2.2 \times 10^{-16}$	Yes
(9)	116.65	5	$< 2.2 \times 10^{-16}$	Yes
(10)	86.341	6	$< 2.2 \times 10^{-16}$	Yes
(11)	105.63	7	$< 2.2 \times 10^{-16}$	Yes
(12)	164.7	6	$< 2.2 \times 10^{-16}$	Yes
(13)	125.6	7	$< 2.2 \times 10^{-16}$	Yes
(14)	87.907	6	$< 2.2 \times 10^{-16}$	Yes
(15)	87.339	7	4.349×10^{-16}	Yes
(16)	66.788	7	6.568×10^{-12}	Yes
(17)	159.75	7	$< 2.2 \times 10^{-16}$	Yes
(18)	105.64	7	$< 2.2 \times 10^{-16}$	Yes

Table A5. Breusch-Godfrey Tests for Serial Correlation

	χ^2 statistic	*df*	*p*-value	Serial Correlation
(1)	418.63	5	$< 2.2 \times 10^{-16}$	Yes
(2)	413.4	5	$< 2.2 \times 10^{-16}$	Yes
(3)	422.16	5	$< 2.2 \times 10^{-16}$	Yes
(4)	167.25	5	$< 2.2 \times 10^{-16}$	Yes
(5)	164	5	$< 2.2 \times 10^{-16}$	Yes
(6)	166.85	5	$< 2.2 \times 10^{-16}$	Yes
(7)	275.52	5	$< 2.2 \times 10^{-16}$	Yes
(8)	277.11	5	$< 2.2 \times 10^{-16}$	Yes
(9)	278.03	5	$< 2.2 \times 10^{-16}$	Yes
(10)	419.24	5	$< 2.2 \times 10^{-16}$	Yes
(11)	412.46	5	$< 2.2 \times 10^{-16}$	Yes
(12)	165.59	5	$< 2.2 \times 10^{-16}$	Yes
(13)	160.23	5	$< 2.2 \times 10^{-16}$	Yes
(14)	271.16	5	$< 2.2 \times 10^{-16}$	Yes
(15)	272.4	5	$< 2.2 \times 10^{-16}$	Yes
(16)	430.91	5	$< 2.2 \times 10^{-16}$	Yes
(17)	185.68	5	$< 2.2 \times 10^{-16}$	Yes
(18)	274.46	5	$< 2.2 \times 10^{-16}$	Yes

Note. The Breusch–Godfrey test used in this study adopts a lag length of 5, aiming to capture potential autocorrelation of the idiosyncratic error term up to the fifth lag.

Table A6. Breusch-Pagan LM Tests for Cross-Sectional Dependence

	χ^2 statistic	*df*	*p*-value	Cross-sectional Dependency
(1)	4828.6	780	$< 2.2 \times 10^{-16}$	Yes
(2)	4799.9	780	$< 2.2 \times 10^{-16}$	Yes
(3)	5023.9	780	$< 2.2 \times 10^{-16}$	Yes
(4)	803.19	190	$< 2.2 \times 10^{-16}$	Yes
(5)	822.56	190	$< 2.2 \times 10^{-16}$	Yes
(6)	793.76	190	$< 2.2 \times 10^{-16}$	Yes
(7)	1131.8	190	$< 2.2 \times 10^{-16}$	Yes
(8)	1092.3	190	$< 2.2 \times 10^{-16}$	Yes
(9)	1233.7	190	$< 2.2 \times 10^{-16}$	Yes
(10)	4812.4	780	$< 2.2 \times 10^{-16}$	Yes
(11)	4864.9	780	$< 2.2 \times 10^{-16}$	Yes
(12)	784.93	190	$< 2.2 \times 10^{-16}$	Yes
(13)	760.93	190	$< 2.2 \times 10^{-16}$	Yes
(14)	1030.5	190	$< 2.2 \times 10^{-16}$	Yes
(15)	1028.7	190	$< 2.2 \times 10^{-16}$	Yes
(16)	5034.7	780	$< 2.2 \times 10^{-16}$	Yes
(17)	911.29	190	$< 2.2 \times 10^{-16}$	Yes
(18)	1105.5	190	$< 2.2 \times 10^{-16}$	Yes