

The Impact of China's Participation in the Value Chains of its Trading Partners on the Carbon Embodied in the Bilateral Trade of Forest Products

Ling Guo Liqiang Xiao Wenlan Wang
Xuanmeng Shi Shuangshuang Wu

Abstract

To recalibrate the connection between participation in global value chains (GVCs) and carbon embodied in trade is of great importance because it provides significant insights about how China's forest products industry should integrate into GVCs and promotes the reduction of carbon embodied in trade. This paper obtains panel data related to the GVC participation of, and carbon embodied in, the trade between China and 43 of its trading partners from 2000 to 2018, and uses fixed effects and quantile regressions to explore the impact of China's participation in the value chains of its trading partners on the carbon embodied in the trade of forest products from the perspective of bilateral trade. It is found that (1) China's participation in the value chains of its trading partners significantly reduces the carbon embodied in forest product trade, especially that of pollution-intensive products (e.g., paper and its products); (2) China's participation in the value chains of high-income countries reduces the carbon embodied in forest product trade; (3) foreign direct investment (FDI) in trading partners weakly suppresses the carbon embodied in the trade of Chinese forest products; (4) the effect on the carbon embodied in the trade of Chinese forest products is only suppressive when China's degree of participation in the value chain is higher; and (5) China's forward participation in the forest product value chains of its trading partners reduces its overall carbon embodied in trade, while the backward participation has the opposite effect.

The booming global production sector has leveraged the rapid development of communications and transportation technologies to form global value chains (GVCs; Zhao et al. 2020). In the context of the current and ongoing increase in global environmental awareness, the discussion on the environmental costs and impacts of GVCs is becoming more pervasive, as is the measurement and study of their "carbon footprint" in the forest products sector (e.g., Lv et al. 2013, Gu et al. 2014). Measuring the value added and carbon embodied in the trade of a particular sector of a country's exports is necessary because trade and environmental policies are often implemented by importing countries to target specific export partners, sectors, or products (Borin and Mancini 2019). Value chain participation can be evaluated through value added decomposition. China's forestry industry has developed rapidly, with its output exceeding US\$1,159.44 billion, trade exceeding US\$160 billion, and labor force exceeding 52 million people in 2020, and it is currently the world's fastest growing country in terms of its production, trade, and consumption of forest products (Hou et al. 2022a). However, Yao and Hou (2016) find that China and Malaysia are at a disadvantage in terms of receiving the

benefits of GVCs because of their relatively low position compared with Canada, the United States, Indonesia, and Russia. Under the foreign trade model of "big in and big out" and "processing trade," China has taken over the low-value-added, energy-intensive, and high-pollution production and manufacturing processes outsourced by multinational companies that dominate the forest product GVCs, which has

The authors are, respectively, PhD Student, School of Economics and Manag., Fujian Agric. and Forestry Univ., Fuzhou, China, and Concord Univ. College, Fujian Normal Univ. Fuzhou, China (stefanieguoling@foxmail.com); Lecturer, Fuzhou Univ. of International Studies and Trade, Fuzhou, China (xiaoliqiang@fzfu.edu.cn); Professor, School of Economics and Manag. Fujian Agric. and Forestry Univ. Fuzhou, China (lincolnshaw84@gmail.com [corresponding author]); and Assistant (Lemon_shi2000@foxmail.com) and Assistant (wssj533@qq.com), Cultural Trade Research Center, Concord Univ. College, Fujian Normal Univ. Fuzhou, China. This paper was received for publication in November 2022. Article no. FPJ-D-22-00062.

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resulted in serious pollution problems. Based on the World Input–Output Database (WIOD), Peng et al. (2022) find that China is a net exporter of carbon to the wood forest products industry and that the furniture industry is responsible for exporting the most CO₂ to its trading partners while the United States exports the most CO₂ to China. Shrestha and Sun (2019) argue that carbon emissions account for approximately 25 percent of the total emissions from production activities, and the emissions intensity of developing countries is usually much higher than that of developed countries. By comparing the carbon storage and emissions of woody forest products, Guo et al. (2010) find that the production, processing, and service life of woody forest products have important impacts on forests, energy, and the greenhouse effect; and that although woody forest products can store carbon, they do not compensate for, or offset, the total CO₂ released during processing in the long run. In September 2020, China clearly proposed the goals of “carbon peaking” by 2030 and “carbon neutrality” by 2060. Does this pose a challenge to China’s forest products sector, which has been already integrated into the GVC? Therefore, this paper examines the carbon embodied in forest products by examining the cross-border trade between China and various of its trading partners and comprehensively assesses the environmental (i.e., carbon) effects brought about by the participation of Chinese forest products in GVCs.

There is an upstream and downstream relationship between sectors within the forest products industry, forming a transnational value-chain system from timber forests to resource-based products, primary processed products, intermediate processed products, and finally deeply processed products. Take paper products, e.g., which transform from the timber mining industry to logs, wood chips, pellets, pulp, paper, paperboard, and finally paper products. According to China Customs, the processing trade of Chinese paper products is mainly based on the process materials supplied by customers; i.e., domestic enterprises use raw, auxiliary, and packaging materials provided by foreign countries, process them into finished products according to the technical requirements agreed by both parties, and then deliver them to the other party. Enterprises only charge processing fees, but the processing trade of man-made boards and wood furniture is mainly based on the processing with imported materials, i.e., purchasing foreign raw and auxiliary materials using Chinese technology, equipment, and labor to process into finished products and then selling them to foreign markets. In the process of participating in GVCs, forest products generate carbon emissions directly and indirectly during the entire production chain of production, processing, manufacturing, and transportation. Multiple mechanisms exist for measuring the environmental impact of developing countries’ participation in GVCs, and the aggregate effect is determined by the interaction between various mechanisms (Lv and Lv 2019). In terms of learning effects, Pietrobelli and Rabellotti (2011) emphasize the positive impact of participating in GVCs and argue that firms can improve their embeddedness and transform and upgrade by leveraging the knowledge flows they enable. In terms of technology effects, Baldwin and Yan (2014) find that participating in GVCs drives technological progress through economies of scale, diversity of intermediate inputs, and quality improvement, which reduces emissions in participating countries. In terms of competitive effects, Wang et al. (2015) point out that in order to enter markets in developed countries, firms in developing countries

must meet the higher energy and environmental protection standards required by developed countries, which will in turn reduce carbon emissions in developing countries. However, some studies also emphasize the negative impact of participating in GVCs (e.g., Wang et al. 2014, Lv et al. 2018), where in the initial stages, the positive impacts of technological progress and industrial restructuring are insufficient to compensate for the increase in pollution caused by rapid expansion. When developing countries participate in GVCs, they are easily subject to low-end locking from developed countries in the dominant position of the value chain, which causes their technological progress to suffer from the “capture dilemma” (Wang et al. 2014). The low-end locking effect experienced by multinational companies in developed countries has tied them to low-value-added, high-pollution links in GVCs, thus exacerbating the increase in the carbon emissions associated with international trade.

This paper examines the impact of China’s participation in the value chains of its trading partners on the embodied carbon of the bilateral trade in forest products by measuring the extent of this phenomenon through value-added decomposition using value chain and environmental indicators and testing its environmental effects through panel data fixed effects and quantile regression models. The novel contributions of this paper are as follows. From the research perspective, this paper explores the relationship between value chains and embodied carbon by taking a sectoral-bilateral trade perspective, whereas the existing studies focus on global- or national-level analyses. In terms of research methodology, the value-added data of forest products subsectors published by the Organization for Economic Cooperation and Development (OECD) are integrated, and the participation as well as the backward and forward participation in forest product GVCs are measured using the industry value-added trade-decomposition technique and matched with the embodied import and export carbon data, which enables the effects of, and mechanisms underlying, value chain participation on carbon embodied in trade to be analyzed through regression models.

Methods and Data

Measurement of key metrics

Measurement of value chain indicators based on sectoral-bilateral dimensions.—By decomposing bilateral exports according to the source of the value added, Borin and Mancini (2019) construct a single sectoral-bilateral flow model of export value added, where multiple entries flows are considered as being “double counted.” Total exports E_{sr} from country of origin s to country r are decomposed by the following:

$$\begin{aligned}
 u_N E_{sr} = & \overbrace{V_s B_{ss}^s E_{sr}}^{\text{domestic value added (DVA}_{sr})}} + \overbrace{V_s B_{ss}^s \sum_{j \neq s} A_{sj} B_{js} E_{sr}}^{\text{domestic double counted (DDC}_{sr})}} \\
 & + \overbrace{\sum_{t \neq s}^G V_t B_{ts}^t E_{sr}}^{\text{foreign value added (FVA}_{sr})}} + \overbrace{\sum_{t \neq s}^G V_t B_{ts}^t \sum_{j \neq s} A_{sj} B_{js} E_{sr}}^{\text{foreign double counted (FDC}_{sr})}} \quad (1)
 \end{aligned}$$

where $B^S = (I - A^S)^{-1}$ is the Leontief inverse matrix after processing. We set the coefficients in the input coefficient matrix A that determine the direct need for intermediate inputs from country s (i.e., $A_{sj} = 0 \forall j \neq s$) to zero; the purpose of doing so is to eliminate the intermediate export links from country s and split the production process along the border of country s . u_N is a $1 \times N$ vector of unit rows and V_s is a $1 \times N$ vector of the share of value added contained in each unit of total output in country s .

In bilateral trade flows, GVC-related trade can be measured by excluding the directly absorbed value-added in exports (DAVAX_{sr}) from country s 's total exports; the result is expressed as GVCX_{sr}, $GVCX_{sr} = u_N E_{sr} - DAVAX_{sr}$. The share of GVCs in bilateral exports is thus expressed by the following:

$$GVC_{sr} = \frac{GVCX_{sr}}{u_N E_{sr}} = \underbrace{\frac{GVCbackward_{sr}}{VS_{sr}}}_{(2)}$$

GVC participation can be decomposed into backward and forward GVC participation, which correspond to the vertical specialization (VS; i.e., the value of imported inputs embedded in exports, or the foreign value added in exports) and VS1 (i.e., the share of exports of intermediate goods that is processed for re-export) indices proposed by Hummels et al. (2001), respectively. These indices are expressed as follows:

$$GVCbackward_{sr} = \frac{V_s(I - A_{ss})^{-1} \sum_{j \neq s}^G A_{sj} B_{js} E_{sr} + \sum_{t \neq s}^G V_t B_{ts} E_{sr}}{u_N E_{sr}} \quad (3)$$

$$GVCforward_{sr} = \frac{V_s(I - A_{ss})^{-1} A_{sr} (I - A_{rr})^{-1} (\sum_{j \neq r}^G Y_{rj} + \sum_{j \neq r}^G A_{rj} \sum_k^G \sum_{l \neq s}^G B_{jk} Y_{kl})}{u_N E_{sr}} \quad (4)$$

where Y_{rj} denotes the final product demand from country j to country r .

Measurement of carbon embodied in trade based on the sectoral-bilateral dimension.—According to Peng and Zhang (2016), the embodied carbon in sector-specific exports from country s to country r (i.e., emissions embodied in export [EEE]) in terms of sector-specific bilateral trade is defined as follows:

$$EEE_{sr} = f_s (I - A_s)^{-1} E_{sr} = f_s B_s E_{sr} \quad (5)$$

The emissions embodied in imports (EEI) in the sector-specific imports from country r to country s are given by

$$EEI_{sr} = f_r (I - A_r)^{-1} E_{rs} = f_r B_r E_{rs} \quad (6)$$

where E_{sr} is the sector-specific export column vector from country s to country r , and E_{rs} is the sector-specific import column vector from country r . f_s is the sector-specific carbon intensity vector from country s and f_r is the carbon intensity vector from the same sector in country r , where both are diagonalized matrices. $B = (I - A)^{-1}$ is the inverse Leontief

matrix. The total carbon embodied in trade is the sum of export and import embodied carbon.

Measurement model setting

We construct the following econometric equation to test the effects of the embodied carbon emissions associated with China's participation in the value chains of its trading partners from a bilateral trade perspective:

$$\ln CO_{2it} = \beta_0 + \beta_1 GVCpt_{it} + \beta_2 Z'_{it} + \lambda_i + \mu_t + \varepsilon_{it} \quad (7)$$

where i and t represent China's trading partner and the year, respectively, $\ln CO_{2it}$ is the logarithm of the embodied carbon of China's exports of forest products to country i , $GVCpt_{it}$ represents the participation of Chinese forest products in the value chain of country i , λ_i represents country fixed effects, μ_t represents time fixed effects, and ε_{it} is the error term. Z'_{it} represents the set of control variables, which contains *trade*, *cie*, *ren*, *goods*, and *fdi*. The detailed descriptions of these variables are explained as follows:

- *trade* represents the bilateral trade volume, using the actual value of forest product trade accounted for by value added. The increase in the scale of economic activities leads to an increase in pollution emissions (Antweiler et al. 2001).
- *cie* represents carbon emissions per unit of energy consumed and is used to measure the average energy efficiency of a country across sectors, which can affect the green productivity of the forest product sector. Improving energy efficiency is one of the most effective ways to address climate change and reduce sectoral emissions (Yao et al. 2021).
- *ren* is the proportion of renewable energy consumption in the forest products sector to total sectoral energy. Increasing the consumption of fossil energy sources such as coal can significantly increase carbon emissions while substituting the use of renewable energy consumption (Sun and Du 2020).
- *goods* represents the openness index measured by the ratio of forest-product value-added exports to output. While trade openness has injected strong impetus into the economy, it has also brought serious resource consumption and pollution emissions (Tamazian and Rao 2010). Trade openness played uncertain roles in carbon emissions reduction in different countries because of its complex effects on production linkage shifting and technology spillover. Therefore, its specific effect on carbon emissions in the forest products sector remains to be investigated.
- *fdi* represents the share of foreign direct investment (FDI) in gross domestic product. FDI will flow within the forestry industry and with other sectors, and if it transfers to dirty industries it will increase environmental pollution and cause "pollution haven effect" (Zhang and Wang 2014). In contrast, if FDI flows to green and technological advanced sectors it will reduce environmental pollutants, which is named "pollution halo theory" (Xu and Deng 2012). Considering the complex effect of FDI on environmental emissions, it implies that the impact of FDI on carbon emissions in national sectors is also imprecise.

Data sources

This paper uses data from the 2000 to 2018 period from China and 43 of its trading partners, which are ranked

among the top countries in terms of exports of forest products and together accounted for nearly 90 percent of global exports in 2018. Sectors related to forest products, which include D16 wood, D17T18 paper and their products, were selected by corresponding OECD inter-country input-output (ICIO) table (OECD 2021) to the International Standard Industrial Classification (UN 2008). The carbon embodied in trade values shown in Table 1 are obtained by adding the data of these two sectors in the OECD database and including them in Eqs. (5) and (6). The GVC-related indexes shown in Table 1 are calculated using the data of the two sectors after matching the OECD ICIO table with the University of International Business and Economics (UIBE) GVC database and substituting them into Equations (2), (3), and (4). Among the control variables, the bilateral trade volume (*trade*) and the ratio of value-added exports of forest products to output (*goods*) are obtained by matching the OECD database with the UIBE GVC database, while the others are obtained from the World Development Indicators database.

Results and Discussion

Analysis of the results of key indicator measurements

Carbon embodied in the bilateral trade of forest products between China and its trading partners.—China is a large trader of forest products and is thus burdened with a high level of embodied carbon in its trading activities. As shown in Figure 1, the largest total amount of embodied carbon resulting from China's trade in forest products among all trading partners in 2018 was from the United States, which released 6.48 million tons, followed by Russia, which released 4.5 million tons. The United States has become China's largest source of embodied CO₂ in this sector with

4.57 million tons, which accounts for 20 percent (i.e., 28.97 million tons) of the total embodied carbon imported and exported from any of the 43 trading partners. Russia, as the second largest importer and exporter of China's embodied carbon, accounts for 4.3 million tons of imported embodied carbon. According to the net export data, China is generally a net importer of carbon embodied in forest products. But China's net exports of embodied carbon to most developed countries are positive, thus indicating that China is a net exporter of forest product embodied carbon while it is a net importer of forest product embodied carbon from developing countries.

To more intuitively show the trend in carbon emissions, the total embodied carbon from international trade in forest products between China and other 10 countries from 2000 to 2018 is selected, as shown in Figure 2. China has always generated the most embodied carbon in trade with the United States in the forest products industry. In its trade with Japan, China's forest products have always created a surplus of embodied carbon. As the terms of trade with Japan have improved, the embodied carbon of forest product exports has been decreasing year by year, and the overall embodied carbon also shows a decreasing trend. Compared with developed countries like the United States and Japan, Russia ranks higher in total embodied carbon because of its yearly increase in embodied carbon imports and even overtakes Japan after 2012 to become the second largest trader of forest product-related embodied carbon in China. Similarly, in trade with Canada, although the change in exported embodied carbon is not significant, the increase in its imported embodied carbon also increases its ranking to third, with 2.03 million tons of total carbon emissions embodied in trade in 2018. Overall, China's trade in forest products to the United States and Japan showed different

Table 1.—Benchmark estimation result.^{a,b} FE is fixed effect. RE is random effect. GMM is Gaussian Mixture Model.

	(1) FE	(2) RE	(3) Consumption-side carbon emissions	(4) ^c GMM
<i>L.lnCO₂</i>				−0.102*** (0.030)
GVC _{pt}	−0.943*** (0.270)	−0.780 (0.548)	−0.416*** (0.0852)	−4.267*** (1.177)
Intrade	0.250*** (0.020)	0.222*** (0.024)	0.0353*** (0.005)	0.240** (0.101)
Incie	0.161*** (0.011)	0.181*** (0.027)	0.033*** (0.002)	0.591*** (0.133)
ren	−0.006*** (0.000)	−0.006*** (0.002)	0.000** (0.000)	0.018*** (0.003)
goods	−0.178 (0.138)	−0.249 (0.304)	0.178*** (0.050)	1.160 (1.029)
fdi	−0.004** (0.001)	−0.003 (0.004)	−0.001*** (0.000)	0.089*** (0.023)
Constant	−0.983*** (0.120)	−0.960*** (0.197)	−0.178*** (0.039)	−3.235*** (0.537)
Observations	817	817	817	798
R-squared	0.454		0.459	
Year fixed effects	Yes	No	Yes	No
Country fixed effects	Yes	No	Yes	Yes
AR(2) P value				0.158
Hansen-test P value				0.113

^a Robust standard errors are in parentheses.

^b * $P < 0.1$, ** $P < 0.05$, *** $P < 0.01$.

^c Column (4) uses the collapse command to limit the number of lags to control the number of instrumental variables.

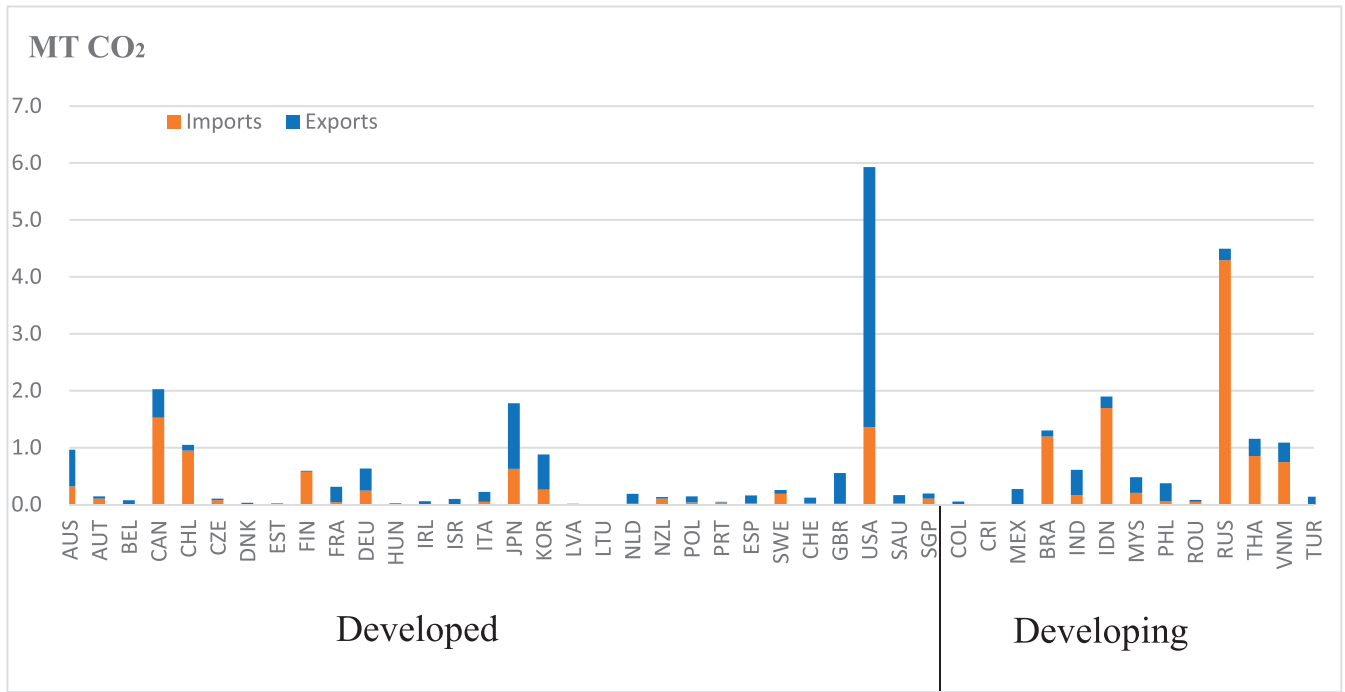


Figure 1.—Comparison of carbon embodied in China's forest product trade to 43 countries under bilateral trade in 2018. (See Appendix A for country abbreviations).

degrees of decline in embodied carbon levels, while almost all other trading partners had a relatively more stable upward trend after the financial crisis in 2008.

The participation of China's forest products in the value chains of its trading partners.—The trend change of China's

participation in the forest product value chains in selected countries from 2000 to 2018 is shown in Figure 3. In the early stages, China had high value-chain participation in Canada's and Indonesia's forest product value chains, at approximately 0.54 and 0.45 in 2000, respectively, but in

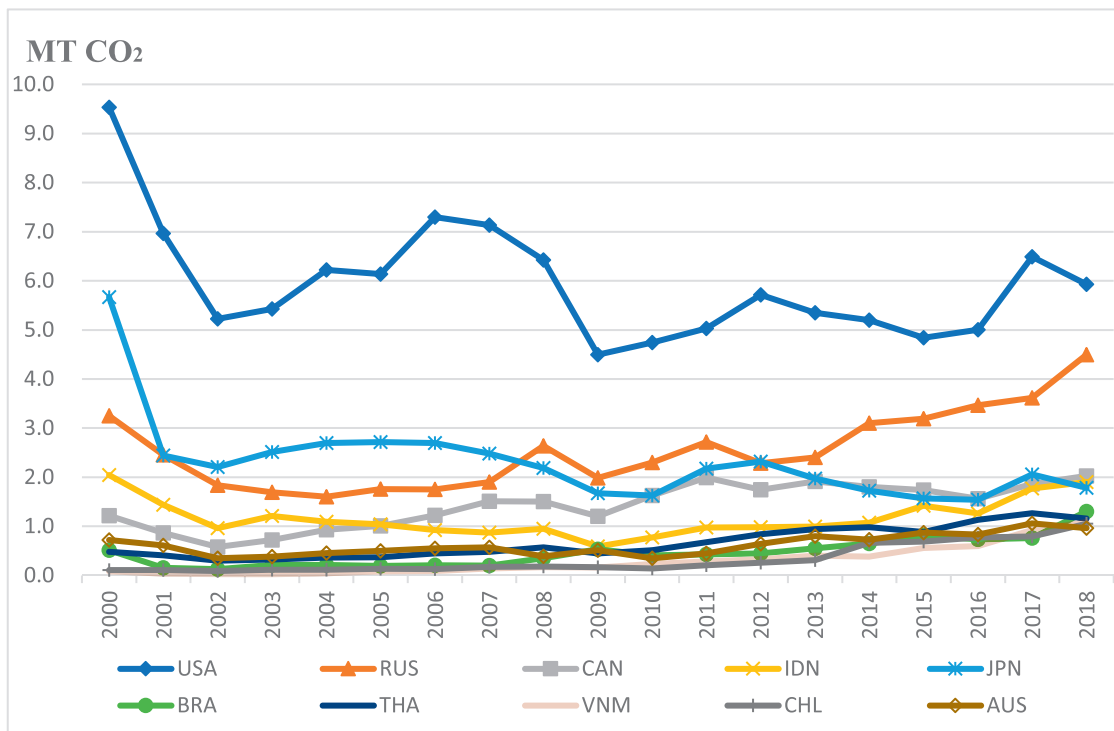


Figure 2.—Trend of carbon embodied in forest product trade between China and 10 countries from 2000 to 2018. (See Appendix A for country abbreviations).

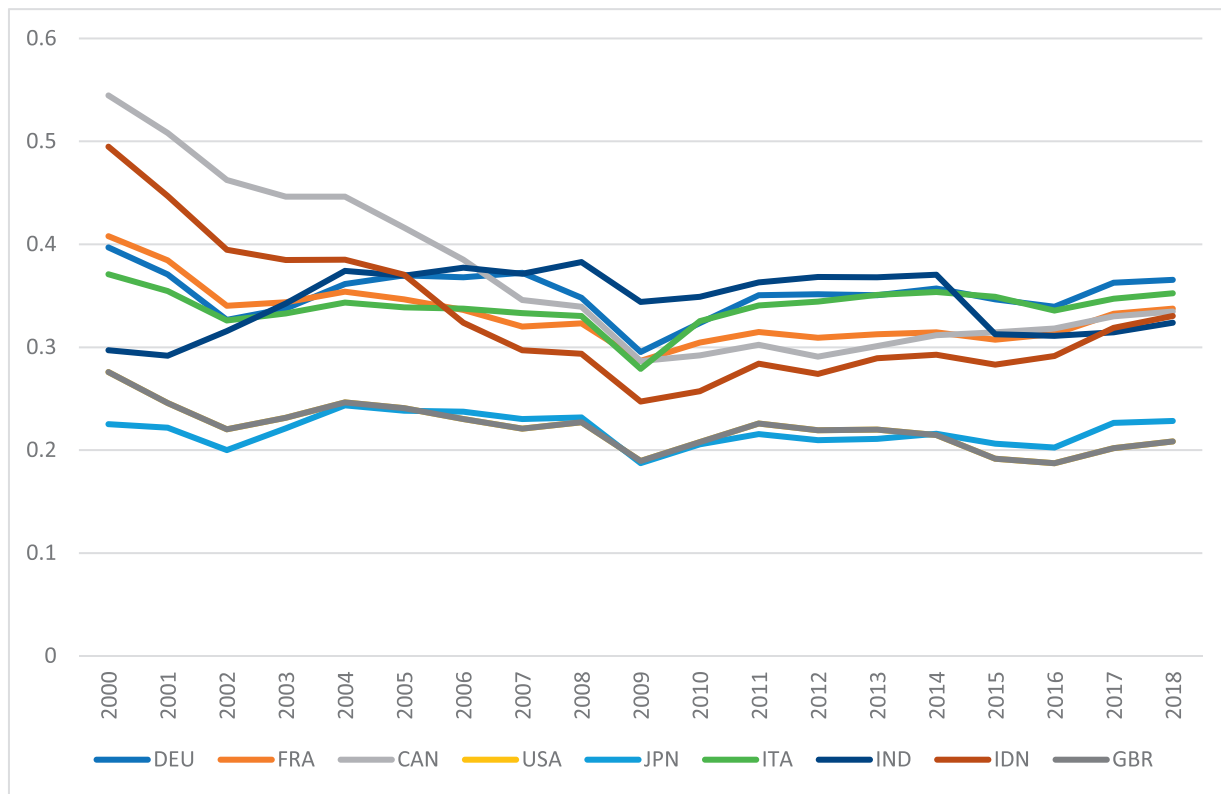


Figure 3.—Trends in value chain participation in China's forest product trade with selected countries, 2000 to 2018. (See Appendix A for country abbreviations).

2018 the highest levels were seen in Germany and Italy. In Japan and the United States, it was approximately 0.22 and 0.25, respectively, in 2000; and in 2018 they still had the lowest value chain participation in China's forest products at 0.23 and 0.21, respectively. However, the United States is the largest market for China's forest product trade. Traditional trade between China and the United States (only involving cross-border final products) accounts for a very large proportion (Jiang et al. 2019), so the share of GVC-related trade (involving cross-border intermediate goods) is smaller. In terms of the overall trend, there was a consistent decline in the value chain participation of each trading partner from 2008 to 2009, and after a recovery from 2009 to 2011, it remains relatively stable with the exception of India.

We now further distinguish between the value chain participation patterns. In 2018, Chinese forest products were significantly more involved in forward value chain participation in Germany, Italy, Canada, France, Indonesia, and India, while in Japan and the United States they were more involved in backward value chain participation, as shown in Figure 4. On average, the difference between China and its nine trading partners in terms of backward participation in the forest product value chain is negligible, and the main difference is in the forward participation in the value chain with each trading partner.

Analysis of baseline regression results

The baseline measurement is based on Model (1), and Table 1 shows the results of the baseline regressions, where (1) to (2) are the results of the fixed-effect and random-

effect regressions. It can be seen that the fixed-effect model outperforms the random-effect model according to the Hausman test. The regression results of the fixed-effects model show that the combined effect of China's participation in the forest product value chains of its trading partners on the environment is negative and significant at the 1 percent level with a coefficient of -0.943 in the first column, thus indicating that it reduces the embodied carbon associated with forest products trade. Specifically, for every 10 percent increase in GVC participation, the logarithm of the carbon embodied in the trade of forest products will be reduced by $0.1 \times 0.943 = 0.094$. It indicates that Chinese forest products can reduce environmental pollution by participating in the value chains of trading partners, which is close to the findings of some scholars. Hou et al. (2022b) found that the economies of scale and structural effects of the Chinese forest products industry's participation in GVCs contribute to the reduction of carbon embodied in trade, but are mainly based on the forward participation model. Lv and Lv (2019) found that the increased level of value chain embedding in China reduces the industry's pollution emissions through positive technology spillover effects, but the effect depends largely on the value chain participation model. This provides the basis for this paper to further investigate different GVC participation patterns. In addition, based on the previous measurement results, we know that the trading countries with the highest and lowest value chain participation in China's forest product value chain in 2018 are Germany and the United States, respectively, so that comparisons can be made. It is found that the forest products trade between China and the United States exhibits a low level of value chain participation at

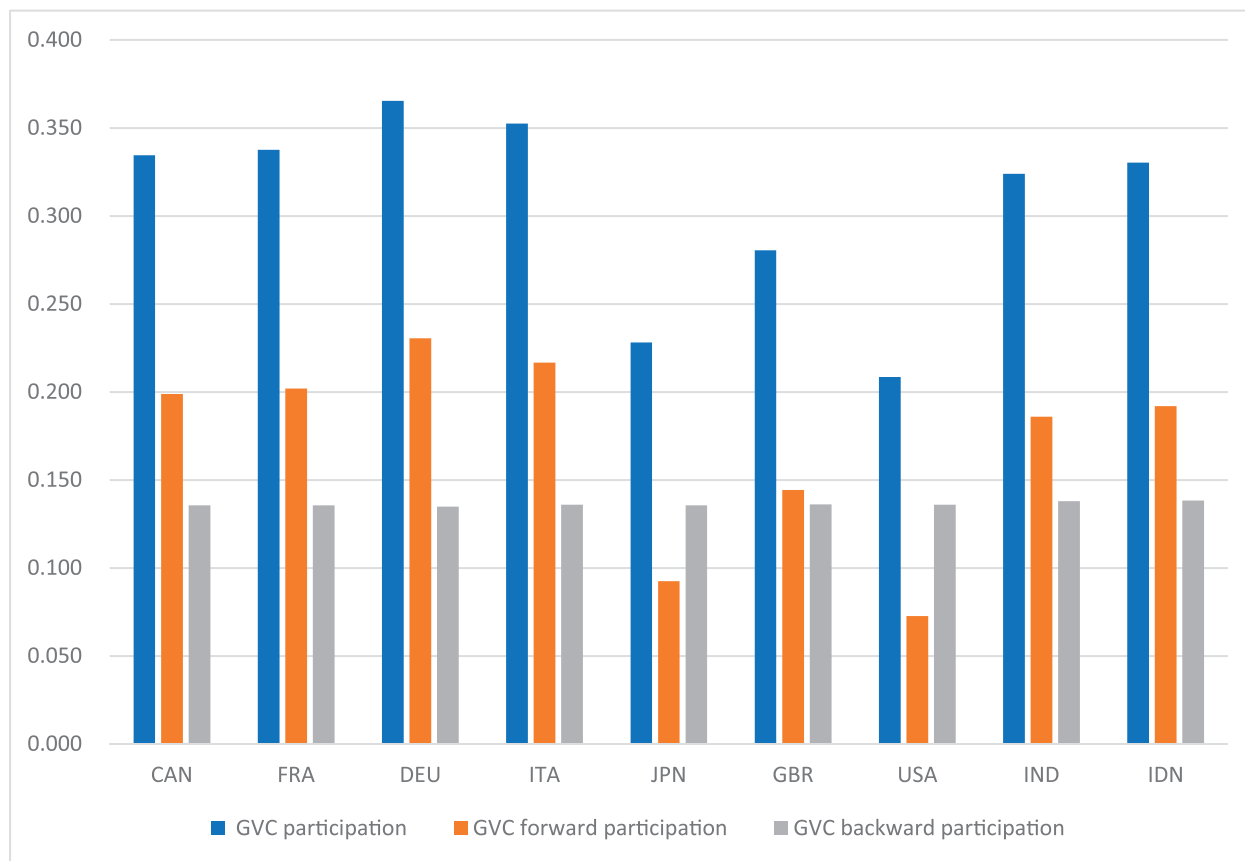


Figure 4.—Level of forward and backward participation in the value chain of China's forest product trade with selected countries in 2018. GVC is global value chain. (See Appendix A for country abbreviations).

0.205 (i.e., the first quartile), while that with Germany exhibits a high degree of value chain participation at 0.367 (i.e., the third quartile). Based on the coefficient results in Column (1) of Table 1, the difference in the degree of value chain participation results in less embodied carbon emissions in Sino-German trade than in Sino-American trade by up to 4.64 percent, which explains 12.99 percent of the embodied carbon gap between the two sets of bilateral trade. This indicates that the impact of value chain participation on the embodied carbon associated with China's forest products trade has a relatively high economic significance.

In terms of control variables, the bilateral trade volume of forest products has a significantly positive effect on China's carbon embodied in trade, thus verifying the environmental impact of trade (Antweiler et al. 2001). The share of renewable energy consumption among China's trading partners shows a significantly negative effect on trade-embodied carbon, and the substitution of renewable energy for fossil fuels and other energy sources will reduce such carbon emissions. The increase of carbon emissions per unit of energy consumption in trading partners increases the carbon embodied in trade to some extent. It indicates that the lower the energy efficiency of the trading partner, the higher the carbon embodied in China's forest product imports. The intensity of foreign direct investment (FDI) is significantly negatively correlated with carbon embodied in trade, thus indicating that foreign direct investment generally helps to reduce such emissions. Although there are scale and structural effects that are detrimental to

reducing carbon emissions, the inhibitory effect on carbon emissions resulting from FDI through the introduction of technology and the subsequent technology spillovers may be stronger (Copeland and Taylor 1994).

Considering that China is one of the largest consumers of forest products, its carbon emissions based on its consumption of forest products is the second largest in the world (Peng et al. 2022). China's demand for forest products has led to changes in the growth of carbon emissions in each of its trading partners, which can thus be used as a proxy indicator of pollution in China's forest products industry using data from the OECD database. As shown in Column (3) of Table 1, using consumption-based carbon emissions (i.e., consumption-side carbon emissions) as the explanatory variable, the effect of China's participation in the forest product value chains of its trading partners on consumption-side carbon emissions is found to be significantly negative at the 1 percent level—i.e., participating in the value chains of its trading partners also suppresses China's consumption-side forest product carbon emissions to some extent.

As shown in Column (4) of Table 1, further regression estimation using the systematic Gaussian Mixture Model (GMM) approach helps to solve the endogeneity of the lagged values of the explained variables. Based on the Hansen test, the original hypothesis of there being no overidentification of the instrumental variables is accepted, which implies that the instrument selection for GMM estimation is valid; based on the AR (2) test, the original hypothesis that there is no second-order serial autocorrela-

tion in the model is accepted, which implies that the estimates of the systematic GMM are consistent. Therefore, it is concluded that China's participation in the forest product value chains of its trading partners significantly reduces the embodied carbon emissions associated with bilateral trade. This is consistent with the findings of Lv and Lv (2019), who show that GVC embedding at the national level significantly reduces the carbon embodied in the trade of the industrial sectors.

Heterogeneity analysis

Analysis based on industrial pollution intensity.—It has been argued that differences in income levels across countries lead to differences in environmental regulations, with high-income countries having higher environmental requirements and greater demand for cleaner products (Bruneau 2008). Therefore, “pollution outsourcing” (i.e., high-income countries outsourcing high-pollution-intensive industries or divisions to developing countries with weak environmental regulations) often occurs and pollution-intensive industries are more likely to be “captured” and embedded in GVCs, thus generating more trade-embodied carbon. Therefore, in pollution-intensive industries, the embodied carbon effect of GVC participation may be negative. According to Busse's (2004) classification criteria for polluting industries, the OECD industries of paper products and printing and publishing (D17T18) are pollution-intensive industries. However, the deepening of China's participation in the global paper industry value chain can instead reduce carbon emissions by increasing its technological level and fixed asset base. The estimated results in Columns (1) and (2) of Table 2 show that the coefficient of influence of GVC participation on the logarithm of embodied carbon associated with bilateral trade in paper and its products is -0.008 , and it is significant at the 1 percent level. The coefficient is 0.003 for wood and

its products, and it is significant at the 5 percent level. These findings indicate that the effect of China's participation in the value chains of its trading partners is more prominent for pollution-intensive products compared with non-pollution-intensive products.

Analysis based on the level of economic development of China's trading partners.—Differences in the energy and environmental intensities of different countries in the GVC affect their environment impact—i.e., there are differences in the environmental impacts of participating countries with different levels of economic development (Arce González et al. 2012). Based on the relevant data from the OECD database, the sample countries were divided into two groups: one for high-income countries ($if_h = 1$) and one for non-high-income countries ($if_h = 0$). The interaction test shows that the developmental level of participating countries has different moderating effects on China's participation in forest product GVCs. The regression results are shown in Column (3) of Table 2. The interaction term of participation in forest product value chains and whether it is a high-income country has a significantly negative effect on the carbon embodied in trade, thus indicating that participating in the value chains of high-income countries reduces the carbon embodied in trade. It suggests that participation in the value chains of high-income countries strengthens the impact of GVC participation on carbon embodied in trade. The reason behind this may be that most high-income countries are Annex I members in the Kyoto Protocol with stricter environmental regulations, which mainly undertake clean and high-value-added production linkages in GVCs (Yu and Luo 2018). Chinese forest products participating in their division system have to strictly comply with forest certification and other environmental standards to reduce the carbon embodied in exports; at the same time, they can also obtain “cleaner” imported

Table 2.—Heterogeneity result.^{a,b}

	(1) Paper and its products	(2) Wood and its products	(3) National development level	(4) Foreign investment entry
GVC _{pt}	-0.008^{***} (0.001)	0.003^{**} (0.001)	-0.532^{**} (0.232)	-1.486^{***} (0.306)
GVC _{pt} × high			-0.408^{***} (0.082)	
GVC _{pt} × fdi				0.090^{***} (0.023)
Intrade	0.121^{***} (0.013)	0.080^{***} (0.007)	0.255^{***} (0.020)	0.247^{***} (0.020)
ln _{cie}	0.101^{***} (0.009)	0.048^{***} (0.006)	0.142^{***} (0.011)	0.160^{***} (0.010)
ren	-0.001^{**} (0.001)	-0.003^{***} (0.000)	-0.008^{***} (0.001)	-0.006^{***} (0.000)
goods	-0.169^{**} (0.067)	-0.764^{***} (0.060)	-0.121 (0.135)	-0.087 (0.138)
fdi	-0.002^* (0.001)	0.000 (0.001)	-0.004^{**} (0.001)	-0.043^{***} (0.010)
Constant	-0.385^{***} (0.082)	-0.162^{***} (0.045)	-0.947^{***} (0.116)	-0.792^{***} (0.148)
Observations	817	817	817	817
R-squared	0.376	0.357	0.456	0.457
Year and country fixed effects	Yes	Yes	Yes	Yes

^a Robust standard errors are in parentheses.

^b * $P < 0.1$, ** $P < 0.05$, *** $P < 0.01$.

intermediate goods from high-income countries to reduce the carbon embodied in imports.

Analysis based on the level of foreign direct investment in the industry.—It is generally believed that foreign direct investment (FDI) affects carbon embodied in trade through industrial transfer, technology spillover, etc. (Copeland and Taylor 1994). Therefore, this paper adds the interaction term between FDI and participation in the forest product value chains of trading partners to the regression equation, and the results are shown in Column (4) of Table 2. The coefficient of the interaction term is positive, and that of China's participation in the forest product value chains of trading partners is negative. Both pass the 1 percent significance level test, thus indicating that the entry of foreign capital from trading partners weakly inhibits the effect of China's participation in the forest product value chains of those trading partners on the overall levels of carbon embodied in trade. The impact of foreign direct investment on the environment brings positive technological effects through technology introduction and diffusion that outweigh the negative scale and structural effects (Sheng et al. 2012). With the enhanced level of foreign investment entry in trading partners, which itself will lead to a reduction of the carbon embodied in China's imports from trading partners, the impact of China's forest products participation in the value chain of trading partners on carbon embodied in trade will be relatively weakened.

Quantile regression.—The above regression results are obtained based on the sample means, but it is unclear whether the conclusions remain robust if different samples are chosen. To answer this question, this section performs a three-quantile sample regression at the 10, 45, and 90 percent levels based on different levels of participation in the forest product value chains of China's trading partners, and the results are significant at both the 10 percent and 1 percent levels, as shown in Columns (1) to (3) of Table 3. However, the embodied carbon effect only shows a significantly negative result at the third quantile, thus indicating that the inhibitory effect of value chain participation on embodied carbon associated with interna-

Table 3.—Quantile regression results.^{a,b}

	10% (1)	45% (2)	90% (3)
GVC _{pt}	0.095* (0.050)	0.143* (0.079)	-14.00*** (1.523)
Intrade	0.058*** (0.003)	0.105*** (0.005)	0.632*** (0.101)
Incie	-0.043** (0.019)	-0.133*** (0.045)	6.266*** (0.866)
ren	-0.000 (0.000)	-0.001** (0.000)	-0.027*** (0.005)
goods	0.006*** (0.002)	0.004 (0.003)	0.783*** (0.033)
fdi	0.001 (0.001)	0.001 (0.001)	-0.030*** (0.008)
Constant	-0.332*** (0.020)	-0.406*** (0.030)	-2.823*** (0.877)
Observations	817	817	817
R-squared	0.441	0.586	0.348
Year and country fixed effects	Yes	Yes	Yes

^a Robust standard errors are in parentheses.

^b * $P < 0.1$, ** $P < 0.05$, *** $P < 0.01$.

tional trade is more prominent for those forest products firms in the sample with a higher degree of participation in the value chains of their trading partners. Lv et al. (2019) also argue that there is a nonlinear effect of GVC participation on carbon embodied in trade under different conversion mechanisms, showing a double-threshold characteristic with successive changes in technology levels.

A further discussion based on the participation model of the forest product value chain

Analysis of different participation models.—The embodied carbon effect created by the heterogeneity of participation in forest product value chains is further examined. The use of intermediate forest product inputs will vary depending on whether forward or backward participation is involved, so the mechanisms of carbon emissions generation also differ. Among them, forward participation indicates the share of intermediate inputs of Chinese forest products in the components exported from other countries; backward participation indicates the share of components from other countries in Chinese exports of forest products.

The regression analyses are conducted separately for the effects of forward and backward participation on the embodied carbon associated with bilateral trade, and the results are shown in Table 4. According to Columns (1)–(3), it can be seen that the effect of forward participation in the value chains of trading partners on the embodied carbon associated with trade in forest products is significantly negative at the 1 percent significance level, which implies that increasing the proportion of Chinese intermediate inputs used in other countries' exports can suppress the

Table 4.—Extended analysis based on embedded patterns.^{a,b} GVC is global value chain.

	(1) Forward GVC participation	(2) Backward GVC participation	(3) Consider both forward and backward GVC participation ^c
GVC _{pt_f}	-2.695*** (0.389)		-2.948*** (0.372)
GVC _{pt_b}		16.007*** (2.927)	20.768*** (2.722)
Intrade	0.150*** (0.020)	0.192*** (0.018)	0.145*** (0.021)
Incie	-0.034*** (0.012)	-0.062*** (0.011)	-0.037*** (0.011)
ren	-0.014*** (0.001)	-0.013*** (0.001)	-0.015*** (0.001)
goods	-0.093 (0.180)	-1.351*** (0.099)	-0.006 (0.164)
fdi	-0.010*** (0.002)	-0.010*** (0.002)	-0.009*** (0.002)
Constant	0.848*** (0.136)	-1.709*** (0.450)	-2.241*** (0.422)
Observations	817	817	817
R-squared	0.209	0.198	0.215
Year and country fixed effects	Yes	Yes	Yes

^a Robust standard errors are in parentheses.

^b * $P < 0.1$, ** $P < 0.05$, *** $P < 0.01$.

^c Significance test of the difference between the forward and backward coefficients: Original hypothesis, $GVC_{pt_b} - GVC_{pt_f} = 0$; alternative hypothesis, $GVC_{pt_b} - GVC_{pt_f} \neq 0$; coefficient difference = 23.716***.

embodied carbon associated with Chinese trade in forest products. The effect of backward participation is significant at 1 percent significance level, which implies a significantly positive effect (i.e., increasing the share of Chinese forest product components in other countries' exports can increase the carbon embodied in the trade of Chinese forest products). This is similar to the findings of Hou et al. (2022b), but the latter was based on the perspective of foreign trade of three segments of China's forest industry, not bilateral trade. Qian et al. (2022) found that GVC forward participation reduces carbon emissions by improving production technology and GVC backward participation increases carbon emissions by increasing the scale of trade from the national level. To better compare the embodied carbon effects arising from the heterogeneity of value-chain participation patterns, both forward and backward GVC participation are included in our model. As shown in Column (3) of Table 4, there is a significant difference between the forward and backward effects on the embodied carbon associated with forest products trade. For every 10 percent increase in China's forward participation in the value chains of its trading partners, the logarithm of the carbon embodied in the trade of forest products will be reduced by 0.2948, while for every 10 percent increase in backward participation, the logarithm of the carbon embodied in the trade of forest products will be increased by 2.0768. Irrespective of whether the difference in the coefficients of these two effects on carbon embodied in trade is significant, further significant difference tests are needed. The results show that there is a significant difference in the environmental impacts of forward and backward participation, which passes the 1 percent significance test.

Heterogeneity analysis based on participation patterns.—The total effect of participating in forest product value chains on trade-embodied carbon has been analyzed. We now analyze effect of different value-chain participation patterns in terms of heterogeneity factors.

From the viewpoint of non-pollution-intensive industries (Table 5), the effect on carbon embodied in trade of forward value chain participation in pollution-intensive products (e.g., paper and its products) is significantly negative, and that in non-pollution-intensive products (e.g., wood and its products) is significantly positive, thus indicating that the positive environmental effect of forward value chain participation is more obvious in pollution-intensive products. The effect on carbon embodied in trade of backward value chain participation in pollution-intensive products is significantly negative, and that in non-pollution-intensive products is significantly positive, thus indicating that China's backward participation in the value chains of its trading partners significantly suppresses the carbon embodied in the trade of pollution-intensive products. In general, both have stronger positive environmental effects on pollution-intensive products than on non-pollution-intensive products. This is not completely consistent with the conclusions of Lv and Lv (2019). Based on national data, they believed that the forward embedding of GVCs has a stronger environmental improvement effect on pollution-intensive industries than on non-pollution-intensive industries, but that backward embedding is easier to be locked in high-polluting production links. This paper considers the carbon embodied in trade including imports, and, most of China's imported products are intermediate inputs with high

Table 5.—Analysis of industry heterogeneity based on participation model.^{a,b}

	Paper and its products		Wood and its products	
	(1)	(2)	(3)	(4)
GVC _{pt_f}	−0.010*** (0.003)		0.003* (0.002)	
GVC _{pt_b}		−1.289** (0.540)		0.260*** (0.022)
Intrade	0.106*** (0.015)	0.131*** (0.012)	0.052*** (0.004)	0.051*** (0.004)
Incie	0.019** (0.008)	0.004 (0.009)	−0.034*** (0.005)	−0.032*** (0.004)
ren	−0.004*** (0.001)	−0.004*** (0.001)	−0.006*** (0.000)	−0.006*** (0.001)
goods	−0.319*** (0.091)	−0.790*** (0.056)	−1.059*** (0.114)	−0.903*** (0.063)
fdi	−0.005** (0.002)	−0.004* (0.002)	−0.002*** (0.001)	−0.002** (0.001)
Constant	0.143 (0.109)	18.477** (7.767)	0.593*** (0.045)	−3.750*** (0.352)
Observations	817	817	817	817
R-squared	0.256	0.247	0.220	0.226
Year and country fixed effects	Yes	Yes	Yes	Yes

^a Robust standard errors are in parentheses.

^b * $P < 0.1$, ** $P < 0.05$, *** $P < 0.01$.

value added, low energy consumption, and low carbon emissions required by processing trade (Wei and Li 2015); therefore, the paper industry may have reduced the carbon embodied in import instead because of the enhanced backward participation.

In terms of economic development, the effect of the interaction term between forward participation in the value chain of Chinese forest products and high-income countries on the carbon embodied in trade is significantly positive at the 1 percent level, which suggests that forward participation in the value chains of high-income countries will increase the carbon embodied in the trade of forest products, as shown in Column (1) of Table 6. However, the effect of the interaction term between backward participation in the value chain of Chinese forest products and high-income countries on the carbon embodied in trade is significantly negative at the 1 percent level, which implies that backward participation in the value chain of high-income countries suppresses the carbon embodied in the trade of forest products. The imported inputs from high-income countries in China's forest product exports may be relatively cleaner than China's own intermediate inputs (Zhao et al. 2017), so backward participation in the value chains of high-income countries can directly reduce carbon embodied in trade. As shown in Table 6, there is a significant difference between the coefficients of the effects of forward and backward participation in developed countries' value chains on the carbon embodied in trade.

From the perspective of FDI, as shown in Column (2) of Table 6, the interaction term between forward participation in the value chain of Chinese forest products and the level of foreign direct investment in trading partners has a significantly positive effect on carbon embodied in trade, thus indicating that foreign direct investment in trading partners weakens the negative relationship between forward participation in trading partners' forest product value chains

Table 6.—Analysis of country heterogeneity and foreign investment entry level heterogeneity based on participation models.^{a,b,c,d}

	National development level (1)	Foreign investment entry (2)
GVC _{pt,f}	-7.250*** (0.546)	-3.731*** (0.410)
GVC _{pt,b}	2.551 (4.251)	20.873*** (2.613)
GVC _{pt,f} × high	6.301*** (0.422)	
GVC _{pt,b} × high	-11.342*** (0.671)	
GVC _{pt,f} × fdi		0.123*** (0.036)
GVC _{pt,b} × fdi		0.009 (0.126)
Observations	817	817
R-squared	0.311	0.222
Year and country fixed effects	Yes	Yes

^a Note: (1) Robust standard errors are in parentheses

^b * $P < 0.1$, ** $P < 0.05$, *** $P < 0.01$.

^c The empirical procedures have all included control variables.

^d Significance test for differences in impact: Original hypothesis, $GVC_{pt,b} \times \text{high} - GVC_{pt,f} \times \text{high} = 0$, and alternative hypothesis, $GVC_{pt,b} \times \text{high} - GVC_{pt,f} \times \text{high} \neq 0$; coefficient difference = 17.643***. Original hypothesis, $GVC_{pt,b} \times \text{fdi} - GVC_{pt,f} \times \text{fdi} = 0$, and alternative hypothesis, $GVC_{pt,b} \times \text{fdi} - GVC_{pt,f} \times \text{fdi} \neq 0$; coefficient difference = 0.114.

and carbon embodied in trade. However, the interaction term between backward participation in the value chain and the level of foreign direct investment in trading partners does not have a significant effect on it. And the result of the significant difference test indicates that there is no significant difference in the impact of FDI on the environment under different participation patterns.

Conclusions

This paper empirically investigates the embodied carbon effect of China's participation in the value chains of its trading partners using the data on embodied carbon emissions and value-added trade between China and 43 countries worldwide from 2000 to 2018 as a sample. A basic regression of the total effect is conducted, and the discussion is based on the industry and country heterogeneity of its trading partners. Furthermore, an extended and in-depth analysis is conducted based on the different effects arising from forward and backward participation in the value chains of China's trading partners. The main research findings are as follows.

(1) China is a net exporter of forest product embodied carbon to most developed countries, while for developing countries China is a net importer of it. The trading partners who participated the most in China's forest product value chain in 2018 were Germany and Italy, and the level of forward participation was higher; China's relationships with Japan and the United States are characterized by lower participation in the forest product value chain, and the levels of backward participation are higher.

(2) Overall, China's participation in its trading partners' value chains significantly suppresses carbon embodied in trade in the forest products industry and most significantly

reduces the carbon embodied in the trade of pollution-intensive products (e.g., paper and its products). China's participation in the value chains of high-income countries suppresses the carbon embodied in the trade of forest products; foreign direct investment in trading partners weakens the suppressive effect of China's participation in the forest product value chains of its trading partners on overall carbon embodied in trade. The quantile regression finds that the effect of China's forest products on carbon embodied in trade is only observed at higher levels of value chain participation.

(3) The sub-value chain participation model yields the following findings. First, the effect of China's forward participation in the value chains of its trading partners on trade-embodied carbon is negative, which implies that the increase of China's share of intermediate inputs in other countries' exports will reduce its carbon embodied in trade, and its backward participation will increase it. Second, China's forward participation in the forest product value chains of high-income countries will increase its carbon embodied in trade. Third, foreign direct investment in trading partners weakens the suppressive effect of forward participation in the value chains of trading partners on the carbon embodied in the trade of Chinese forest products. Finally, the suppressive effect on carbon embodied in trade of pollution-intensive products (e.g., paper and its products) is stronger for both forward and backward participation in value chains compared with non-pollution-intensive products (e.g., wood and its products).

For China—a net importer of forest product-related embodied carbon—a more comprehensive integration into GVCs is not only beneficial to those value chains, but also to reducing the carbon embodied in the trade of forest products. In this regard, it should focus on the suppressive effect on carbon embodied in trade brought about by forward value chain participation and increasing the proportion of indirect exports of Chinese forest products. However, the decline in domestic value added will increase the carbon embodied in the trade of Chinese forest products; therefore, increasing local enterprises' value added can better drive technological upgrading and the environmental protection standards associated with domestic forest products. China should especially reduce the carbonization of paper products, improve the recycling rate of waste paper products, and encourage paper enterprises to use nonwood fiber materials. Furthermore, it should actively build a low-carbon certification system for paper products, improve the traceability of paper products, and control the entire production process of paper products to reduce its carbonization.

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Appendix A.—Abbreviations of countries or regions studied in this article.

Code	Country
AUS	Australia
AUT	Austria
BEL	Belgium
BRA	Brazil
CAN	Canada
CHE	Switzerland
CHL	Chile
COL	Colombia
CRI	Costa Rica
CZE	Czech Republic
DEU	Germany
DNK	Denmark
ESP	Spain
EST	Estonia
FIN	Finland
FRA	France
GBR	Britain
HUN	Hungary
IDN	Indonesia
IND	India
IRL	Ireland
ISR	Israel
ITA	Italy
JPN	Japan
KOR	Korea, Rep.
LTU	Lithuania
LVA	Latvia
MEX	Mexico
MYS	Malaysia
NLD	Ireland
NZL	New Zealand
PHL	Philippines
POL	Poland
PRT	Portugal
ROU	Romania
RUS	Russia
SAU	Saudi Arabia
SGP	Singapore
SWE	Sweden
THA	Thailand
TUR	Turkey
USA	America
VNM	Vietnam