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Original Paper

Does strict environmental regulation enhance the global value chains position of China's industrial sector?

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ABSTRACT

Given the vital importance of global value chains (GVCs) position for a country's international competitiveness, this paper tries to investigate the impacts of environmental regulation on the GVCs position of China's industrial sector. Using the latest value-added decomposition method, we first measure the GVCs position of China's industrial sector from 2003 to 2014. Subsequently, both two-stage least squares (2SLS) method with panel data and mediating effect model are employed to empirically examine the effects of environmental regulation on China's position in GVCs. The results indicate that environmental regulation has significantly upgraded the GVCs position of China's industrial sector, and the effect is more evident for the sub-sectors with originally lower GVCs position. The mediation effect test shows that increasing R&D investment is an important channel through which environmental regulation affects the GVCs position of China's industrial sector, which verifies the existence of the Porter hypothesis. Further analysis finds that the enhancement of GVCs position of China's industrial sector caused by environmental regulation is mainly achieved through reducing the backward GVCs position.

1. Introduction

China has achieved dramatic economic growth since its reform and opening-up in the late 1970s. According to World Bank Open Data, China's total GDP has increased from 293.63 USD billion in 1978 to 11.785 USD trillion in 2020, increasing by nearly 39 times and which has made China the world's second-largest economy. As one of the most important driving forces of economic growth, China's foreign trade has also made remarkable progress (Wang et al., 2015; Hye et al., 2016). According to WTO statistics, China replaced the United States for the first time in 2013 as the world's largest merchandise trader. However, the rapid growth of China's foreign trade has brought about serious environmental problems (He, 2006; Sun et al., 2019a).

In the context of increasing environmental protection awareness, more and more attention has been paid to the relationship between international trade and environmental issues (LaPlue, 2019; Sun et al., 2020). To protect domestic environment quality while expanding international trade, various environmental regulations have been widely carried out by governments across the world (Shi and Xu, 2018). In this regard, there is a concern that environmental regulation would exert a malign influence on the international competitiveness of domestic industries, especially for the countries whose exports are usually energy-hungry and heavily polluting during their production (Wang et al., 2015). Therefore, to explore the impact of environmental regulation on the export competitiveness of China's industrial sector has both theoretical and practical significance.

Despite the wide research on the relationship between environmental regulation and international competitiveness, there is no consensus across current studies (Ghani, 2012). Some studies pointed out that environmental regulation will lead to a decline in the export competitiveness of domestic industries by increasing production costs (Hwang and Kim, 2017; Shi and Xu, 2018; Du and Li, 2019). However, abundant literature holds the opposite view that environmental regulation may have a positive impact on international trade. They believe that environmental regulation can cause an increase in environmental innovation, thereby reducing production costs (Testa et al., 2011; Rubashkina et al., 2015; Brandi et al., 2020). Another class of literature finds the impact of environmental regulation on international competitiveness varies in different countries and industries, depending on the realities of the

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situation (Larson et al., 2002; Wang et al., 2018; Borsatto and Amui, 2019).

The fragmentation of production over the last two decades considerably altered the patterns of international trade. With the deepening of the global production networks, GVCs has been gradually formed. The production processes of the final products have increasingly been fragmented across national borders (Timmer et al., 2015), and offshoring is becoming more and more popular. Unlike the traditional international production system emphasizing that a country produces and exports final products with comparative advantages, the GVCs system decomposes the production of final products into multiple production links (Hummels et al., 2001). Substantial variations occur in terms of resources and profit gains for countries occupying different positions in the GVCs (Liu et al., 2018). Specifically, the countries on the upstream of GVCs occupy both ends of the smiling curve, which are responsible for high value-added and low-carbon production links such as research and development, design and high-tech components of a product. In contrast, the countries positioned the downstream of GVCs are mainly engaged in low value-added production links such as low-tech, high-energy-consumption parts processing, and assembly (Yu and Luo, 2018; Sun et al., 2019b).

As one of the most important world factories, China has been deeply embedded in the GVCs. Therefore, studying environmental regulation on China's industrial competitiveness from the perspective of GVCs is extremely important, because it can not only effectively avoid the statistical errors that may exist in traditional trade indicators (Jakubik and Stolzenburg, 2018), but also more accurately measure China's industrial competitiveness in today's globalized production networks (Koopman et al., 2014). However, very few studies pay their attention to this field. Xie et al. (2018) proves that strict environmental regulation will impose a significant negative impact on the position of GVCs based on a study of 45 OECD countries. Taking the Chinese industrial enterprises as a study sample, Wang et al. (2019) finds that environmental regulation is conducive to the improvement of the quality of export products and the position of the GVCs. Based on the panel data of 40 countries from 2007 to 2014, Xu and Zhang (2020) finds that there is a U-shaped relationship between the stringency of environmental regulation and GVCs position. Although the above studies have made some contributions to existing literature, no consistent conclusions have been reached.

The major contributions of this paper to the related literature lie in the following three aspects: First, the latest value-added decomposition method is used to measure the GVCs position of China's industrial sector in the current international trade system. In order to make a more comprehensive analysis, the GVCs position of China's industrial sector is further subdivided into two parts including the forward GVCs position and the backward GVCs position. Second, we empirically examine the impact of environmental regulation on the GVCs position of China's industrial sector by employing two-stage least squares (2SLS) method and panel data quantile regression, which reveals that environmental regulation has significant effects on GVCs position of China's industrial sector. Moreover, the heterogeneous impacts of environmental regulation on the forward and the backward GVCs positions are also investigated. Third, a mediating effect model is used to probe the impacting mechanism of environmental regulation on the GVCs position. We find that increasing R&D investment is an important channel through which environmental regulation promotes the GVCs position of China's industrial sector, which well verifies the existence of the Porter hypothesis.

The rest of this paper is arranged as follows: Section 2 theoretically discusses the potential impacts of environmental regulation on the position of GVCs and its underlying mechanism; Section 3 introduces the construction of GVCs position index and the dataset, and reports the results of the GVCs position; Section 4 empirically investigates the impact of environmental regulation on the GVCs position of China's industrial sector as well as its underlying mechanism; Section 5 concludes the paper and puts forward some useful policy recommendations.

2. Theoretical mechanism

Theoretical research on the relationship between environmental regulation and international trade is mainly based on the following two hypotheses: one is the pollution haven hypothesis, which holds the viewpoint that environmental regulation will increase the production costs of enterprises, so as to reduce the industrial competitiveness in international trade. The other is the Porter hypothesis, which believes that environmental regulation can enhance the international competitive advantage of domestic products by stimulating enterprises to improve their innovation capabilities, and this can generate some innovation compensation effects and offset the compliance costs resulting from the environmental regulation.

In the era of GVCs, integrated production form fades and product production processes are normally fragmented into two or more links. Countries with different GVCs positions undertake different production links (Fig. 1). Considering that most industries in China are still in the downstream of GVCs, which are mainly engaged in the export of raw materials and the assembly of intermediate products produced by other countries, the formulation and implementation of environmental regulation will impose significant effects on the GVCs positions of China's industrial sector. On the one hand, environmental regulation can provide incentives to change the enterprise's production in ways that lead to the upgrading of industrial chains through decreasing resource inputs and/or increasing efficiency (Testa et al., 2011). Moreover, the innovation triggered by which may enhance the capacity to produce high-tech intermediate goods, leading to the promotion of the industry's GVCs position (Qiu et al., 2018). On the other hand, environmental regulation will inevitably result in additional expenditure of enterprises pollution control costs, which may lead to a reduction in the enterprise's investment in production factors such as research and development and high-quality labor force (Ouyang et al., 2020). More importantly, the increase in production costs may lead to a decrease in corporate profitability; in order to maximize their profits, enterprises may transfer pollution-intensive production links to areas with relatively weaker

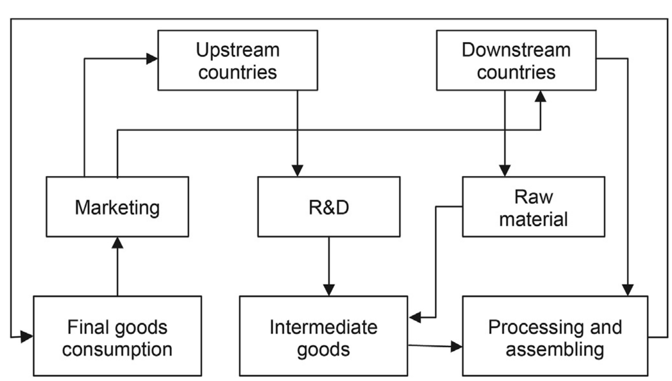

Fig. 1. Operation of the global value chains system.

environmental regulation and replace them by importing intermediate products from other countries (Cole and Elliott, 2003b; Cui and Moschini, 2020). As a result, the completeness of China's industrial chain has declined, which has further reduced its position in the GVCs.

According to the construction method of GVCs position measurement index, it can further be subdivided into forward GVCs position index and backward GVCs position index. Forward GVCs position refers to the weighted value of the proportion of total exports processed by the importing country and exported to other countries in total exports, measuring the core competitiveness of the country's industry in international trade; backward GVCs position refers to the foreign added value contained in exports measuring the completeness of the industry chain in the country, i.e., the length of the industry chain (Koopman et al., 2014; Wang et al., 2017; Sheng and Jing, 2019). In this context, the implementation of environmental regulation will enhance the GVCs position in two ways: on the one hand, the innovation willingness of heavy polluting enterprises along with their innovation capacity will increase under environmental regulation, which may greatly enhance the international competitiveness of a country's core intermediate products in the industry, and also promote the forward GVCs position index of the industry. On the other hand, by learning advanced foreign technologies, domestic enterprises will continuously improve their independent innovation capabilities, and then replace the foreign products contained in the final product, which will reduce the backward GVCs position. Both of these methods will enhance the GVCs position of domestic industries.

At the same time, the compliance costs of enterprises caused by environmental regulation may also make related industries further expand their backward GVCs position, because enterprises may reduce production scale or even transfer pollution-intensive production links overseas while replacing them with a large number of imported foreign intermediate products. This will shorten the domestic industry chain and make the overall position of GVCs continue to decline.

Overall, the above analysis shows that the impact of environmental regulation on GVCs position is far from straightforward. In order to investigate this impact along with its underlying mechanism more accurately, in what follows we conduct some empirical studies taking China's industrial sector as the research sample.

3. Measurement of GVCs position of China's industry sector

3.1. Construction of GVCs position index

In recent years, GVCs has become a very hot topic. More and more scholars have explored the position of different countries in international trade from the perspective of GVCs, and the measurement indicators and calculation methods on GVCs position have also been continuously developed. The input-output analysis method first proposed by Leontief (1936), and especially the Leontief Inverse Matrix, became the theoretical basis of GVCs decomposition. Koopman et al. (2010) made a pioneering work in this field, which constructs an indicator reflecting the division of labor and the degree of participation of a country's industry in GVCs by dividing the domestic added value of a country's export products into five parts. Wang et al. (2013) and Koopman et al. (2014) further detailed the reasoning process of decomposing the GVCs, which well solved the double-counting problem in the trade.

Following the calculation method of the GVCs position index (GVCs_P) proposed by Koopman et al. (2010), this paper defines the country-sector level GVCs_P as the log ratio of a country sectors supply of intermediates used in other countries exports to the use of imported intermediates in its production. Further, we subdivide the GVCs position index into two components including the forward GVCs position (GVCs_PF) and the backward GVCs position (GVCs_PB). The larger the forward GVCs position index is, the more this country tends to export intermediate products. The larger the backward GVCs position is, the more this country tends to engage in low value-added tasks such as assembly (Sheng and Jing, 2019). The mathematical expression is as follows:

$$\mathrm{GVCs\_P}_r^i = \mathrm{GVCs\_PF}_r^i - \mathrm{GVCs\_PB}_r^i = \mathrm{Ln}\left(1+\frac{\mathrm{IV}_r^i}{\mathrm{uE}_r^i}\right) - \mathrm{Ln}\left(1+\frac{\mathrm{FV}_r^i}{\mathrm{uE}_r^i}\right) \quad (1)$$

In order to avoid the double-counting problem of the measurement proposed by Koopman et al. (2010), this paper adopts the method of value-added decomposition following Koopman et al. (2014), which decomposed the value-added of a country's total export as follows:

$$\begin{aligned}\mathrm{uE}^{i*} =& \mathrm{V}^i\sum_{j\neq i}\mathrm{B}^{ii}\mathrm{Y}^{ij}+\mathrm{V}^i\sum_{j\neq i}\mathrm{B}^{ij}\mathrm{Y}^{jj}+\mathrm{V}^i\sum_{j\neq i}\sum_{t\neq i,j}\mathrm{B}^{ij}\mathrm{Y}^{jt}+\mathrm{V}^i\sum_{j\neq i}\mathrm{B}^{ij}\mathrm{Y}^{ji}\\ &+\mathrm{V}^i\sum_{j\neq i}\mathrm{B}^{ij}\mathrm{A}^{ji}\left(\mathrm{I}-\mathrm{A}^{ii}\right)^{-1}\mathrm{Y}^{ii}+\mathrm{V}^i\sum_{j\neq i}\mathrm{B}^{ij}\mathrm{A}^{ji}\left(\mathrm{I}-\mathrm{A}^{ii}\right)^{-1}\mathrm{E}^{i*}+\sum_{t\neq i}\sum_{j\neq i}\mathrm{V}^t\mathrm{B}^{ti}\mathrm{Y}^{ij}\\ &+\sum_{t\neq i}\sum_{j\neq i}\mathrm{V}^t\mathrm{B}^{ti}\mathrm{A}^{ij}\left(\mathrm{I}-\mathrm{A}^{jj}\right)^{-1}\mathrm{Y}^{jj}+\sum_{t\neq i}\mathrm{V}^t\mathrm{B}^{ti}\mathrm{A}^{ij}\sum_{j\neq i}\left(\mathrm{I}-\mathrm{A}^{jj}\right)^{-1}\mathrm{E}^{j*}\end{aligned} \quad (2)$$

In Eq. (2), the exports of a country's gross added value is divided into nine components, and the classifications and definitions of each component are shown in Table 1.

In Eqs. (1) and (2), uE_r^i, represents the gross value-added export of r industry in the country i, $\mathrm{IV}_r^i = \mathrm{V}^i\sum_{j\neq i}\sum_{t\neq i,j}\mathrm{B}^{ij}\mathrm{Y}^{jt}$, represents the domestic value-added in intermediate exports of r industry in the country i. These intermediate products are used by the direct importer to produce exports ultimately consumed by other countries except i, excluding the domestic double counted portion caused by the back and forth intermediate trade to produce intermediate exports. $\mathrm{FV}_r^i = \sum_{t\neq i}\sum_{j\neq i}\mathrm{V}^t\mathrm{B}^{ti}\mathrm{Y}^{ij} + \sum_{t\neq i}\sum_{j\neq i}\mathrm{V}^t\mathrm{B}^{ti}\mathrm{A}^{ij}(\mathrm{I}-\mathrm{A}^{jj})^{-1}\mathrm{Y}^{jj}$, represents the total foreign value-added embodied in the country i's r industry, excluding the double counted portion in the gross exports originating from foreign countries (Wang et al., 2013).

3.2. Data sources

This paper is based on the 2016 World Input-Output Database (WIOD),[1] which includes multiple sub-databases such as WIOT, Socio-economic Account (SEA), and Energy Account. Among them, the WIOT database provides a 15-year (2000–2014) continuous series data of 56 industries in 44 countries (or regions), including all the industry categories in the ISIC Rev 4.0. This table summarizes all the transactions between industries and even the end-users globally, which captures the entire flow of input factors for each industry in each country, including intermediate goods and the final products, and well reflects the current world economic and trade structure. SEA mainly contains data on employment, capital stocks, gross output, and value-added at current and constant prices at the industry level. By combining the WIOD database with China Statistical Yearbook and China Statistical Yearbooks on

[1] http://www.wiod.org.

Table 1
Accounting of gross value-added exports: Concepts.

Gross value-added exports (uE)	Domestic content (DC)	Value-added exports (VT)	(1) DV in direct final goods exports (2) DV in intermediate exports absorbed by direct importers (3) DV in intermediate reexported to third countries IV
		Domestic content in intermediate exports that finally return home (VS1*)	(4) DV in intermediate that return via final imports (5) DV in intermediate that return via intermediate imports (6) Double counted intermediate exports produced at home
	Foreign content (VS)		(7) FV in final goods exports (8) FV in intermediate goods exports (9) Double counted intermediate exports produced abroad

Note: Koopman et al. (2014), modified.

Environment, we integrate all the 36 industrial sub-sectors in China into the ISIC Rev 4.0 classification, covering a total of 20 industrial sub-sectors shown in Appendix A.

3.3. Results of GVCs position index

The results of the GVCs position index of China's industrial sector are shown in Fig. 2. Overall, the GVCs_P of each sub-sector in China is negative over the study period, which indicates that most of China's industrial sub-sectors are still in the middle or low reaches of the global value chains, being engaged in processing and assembly of intermediate goods produced in other countries with low added value and high energy and environmental costs. When we look into the variation trends, the GVCs_P of most studied sub-sectors are on the rise, such as other non-metallic mineral products (S11), and transport equipment (S17), whose GVCs position index has turned positive in 2014, indicating that China has achieved a continuous upgrade of its industrial sector. Specifically, GVCs position index for the labor-intensive and/or resource-intensive industries are relatively higher, such as food products, beverages and tobacco products (S2), textiles, wearing apparel and leather products (S3), and wood and products of wood and cork (S4). This is because these industries are not highly involved in globalization and their domestic production chains are relatively complete. In contrast, the GVCs position index of capital-intensive and/or technology-intensive industries is relatively lower.

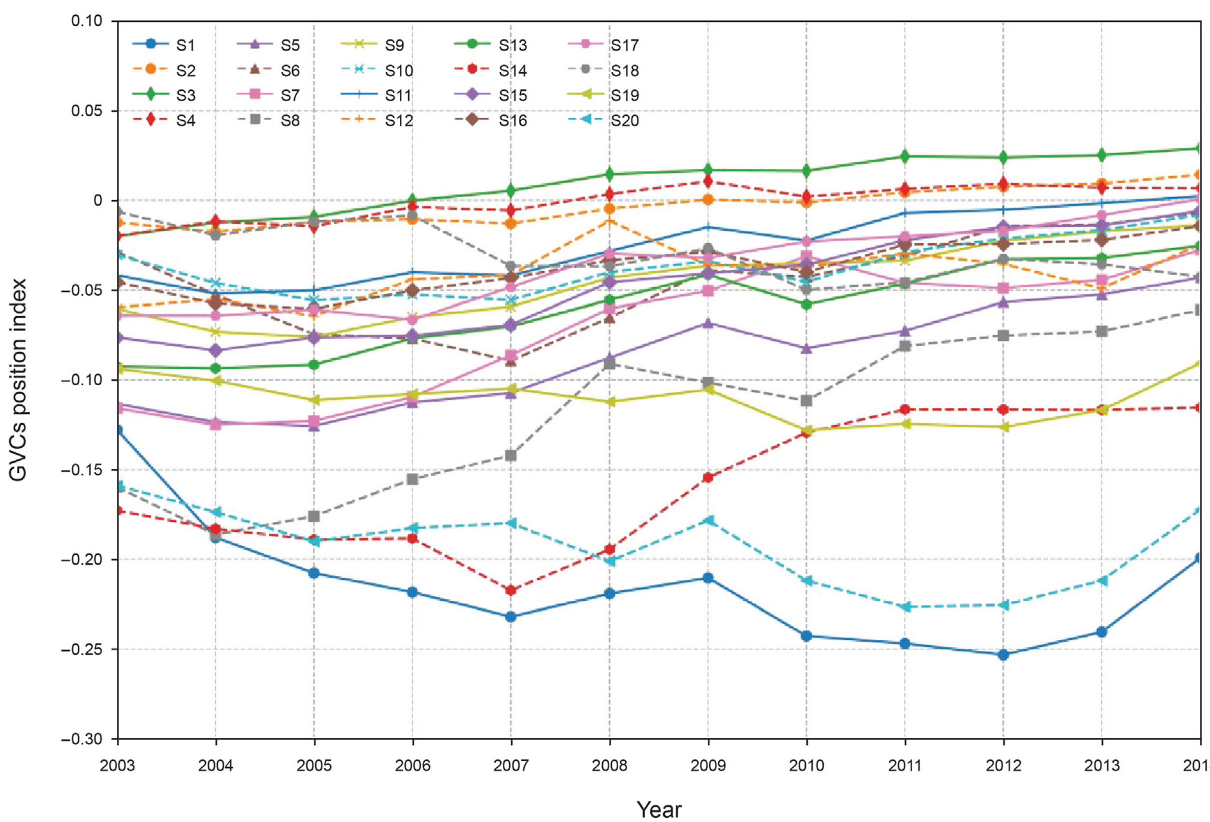

Fig. 2. GVCs position index of China's industrial sector.

4. Empirical results and discusses

4.1. Econometric model, variables and data

The primary aim of this paper is to investigate the impact of environmental regulation on the GVCs position of China's industrial sector. Based on the above theoretical analysis, the regression model is built as follows:

$$\mathrm{GVCs\_P}_{it} = \alpha + \beta_1 \mathrm{lner}_{it} + \beta_2 \mathrm{lngopi}_{it} + \beta_3 \mathrm{va}_{it} + \beta_4 \mathrm{lnkemp}_{it} + \beta_5 \mathrm{lnw}_{it} + \beta_6 \mathrm{lnxl}_{it} + \beta_7 \mathrm{open}_{it} + \beta_8 \mathrm{lnfdi}_{it} + \varepsilon_{it} \quad (3)$$

The explained variable in this paper is the GVCs position index of China's industrial sector, and the explanatory variable is the environmental regulation intensity of each industrial sub-sector. The environmental regulation intensity mainly involves the cost of implementing the regulation, such as pollution abatement and control expenditure (PACE). Following Cole and Elliott (2003a), Lanoie et al. (2011), and Zhao et al. (2018), this paper measures the intensity of environmental regulation (ER) using the ratio of the industrial pollution abatement and control expenditure (the sum of annual expenditures of industrial wastewater treatment facilities and industrial waste gas treatment facilities for various industries) to their corresponding sales values. The larger ER is the higher intensity of environmental regulation for this industry.

In order to exclude the influences from other determinants on the final results, we include a vector of industry-level control variables in Eq. (3) as follows: (1) relative size of the industry (lngopi) represented by the gross industrial output value based on 2010; (2) Gross value added (va), which represents the profitability of the industry by taking 2010 as the base year; (3) Physical capital intensity (lnkemp) expressed by net fixed assets per capita (capital stock/number of employees); (4) Labor wage level (lnw): represented by labor compensation income divided by employment; (5) Labor productivity (lnxl) represented by the total industrial output value divided by the number of employees; (6) Trade openness (open) measured by the proportion of total imports and exports to the total output; (7) Foreign direct investment (lnfdi) expressed as the capital stock of foreign direct investment.

All the basic data is collected from WIOD (2016), China Statistical Yearbooks, China Statistical Yearbooks on Environment, and China Industry Statistical Yearbooks. Considering that the dataset on China's environmental regulation is only accessible since 2003, this paper integrates the above database to obtain panel data of China's 20 industrial sectors from 2003 to 2014. Table 2 summarizes the descriptive statistics of the key variables used in this study.

Table 2
Descriptive statistics of variables.

Variable	N	Mean	Std. Dev.	Min	Max
GVCs_P	240	−0.067	0.065	−0.253	0.029
GVCs_PF	240	0.062	0.012	0.020	0.089
GVCs_PB	240	0.129	0.066	0.025	0.230
lner	240	−2.079	1.294	−5.735	0.464
lner2	240	−2.303	1.274	−4.899	0.325
lngopi	240	4.596	0.207	3.848	5.365
va	240	1.093	0.326	0.201	3.962
lnkemp	240	5.455	1.048	3.680	8.187
lnw	240	3.539	0.770	1.765	7.677
lnxl	240	5.904	0.875	3.849	8.645
lnfdi	240	4.526	1.315	0.193	7.477
open	240	0.138	0.149	0.003	0.691
lnc	240	8.137	1.426	4.890	10.983
lnrca	240	0.156	0.515	−1.202	1.223
rd	240	0.010	0.025	0.000	0.359
df	240	3.459	2.909	0.144	17.817

4.2. Results and discussions

4.2.1. Results of the OLS estimation

According to Eq. (3), the panel data of 20 sub-sectors from 2003 to 2014 is used to examine the impact of environmental regulation on the GVCs position of China's industrial sector with OLS estimation. Column (1) in Table 3 shows the results without considering the control variables. To further test the robustness of the results, control variables are added one after another and the empirical results are respectively reported in Columns (2) to (8). It can be seen that the regression coefficients of the explanatory variable in Columns (1) to (8) are all positive and statistically significant at the 1% critical level, implying that environmental regulation have significantly enhanced the GVCs position of China's industrial sector during the studied period, and this effect is very robust and stable.

Among the control variables, the regression coefficients of the total industrial output value and labor productivity are significantly positive, which indicates that expanding the industry scale and increasing labor productivity can effectively improve the position of GVCs. On the contrary, the regression coefficients of the per capita fixed capital stock, wages, and openness are all negative and statistically significant. The negative correlation between per capita fixed capital stock and GVCs position index implies that increasing capital investment is no longer a good way to enhance the position of GVCs in China's industrial sector. The underlying reason for the negative regression coefficients of wage level is that the increase in labor wage leads to a rise in the production cost of enterprises, so as to reduce the international competitiveness as well as the position of GVCs in China's industrial sector. The significant negative correlation of openness is due to the low position of GVCs in most subsectors in China, which is mainly engaged in the assembly and production of a large number of imported foreign intermediate products, reducing the proportion of domestic value-added and thus reducing the position of GVCs.

4.2.2. Robustness test

To further test the robustness of the regression results, we use the following three methods:

The first one is to treat the potential endogeneity problem using two-stage least squares (2SLS) estimation. The prerequisite for estimation consistency of the OLS estimation is that the explanatory variables are all exogenous. However, the causal relationship between environmental regulation and GVCs position may be bidirectional (Levinson and Taylor, 2008), which fails to satisfy the conditions of estimation consistency. To solve this problem, two types of instrumental variables are selected in this paper to address the potential endogeneity problem.

First, according to the method of Fu and Li (2010), this paper selects the total energy consumption (lnc) of China's industry as an instrumental variable for environmental regulation. This is because the total energy consumption of various industries is closely related to the intensity of environmental regulation. Secondly, referring to Zhao et al. (2018), we use the first-order and second-order lag of environmental regulation stringency as instrumental variables, which can effectively alleviate the reverse causality and simultaneous causality.

Table 4 reports the empirical results of the 2SLS estimations, of which Column (1) shows the results of instrumental variables represented by the total energy consumption (lnc), Columns (2) and (3) show the results of instrumental variables represented by the first-order and second-order lag of environmental regulation,

Table 3
Results of the OLS estimation.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
lner	0.016*** (0.003)	0.014*** (0.003)	0.015*** (0.003)	0.009*** (0.002)	0.008*** (0.002)	0.010*** (0.003)	0.010*** (0.003)	0.014*** (0.003)
lngopi		0.029** (0.013)	0.051*** (0.014)	0.077*** (0.014)	0.090*** (0.016)	0.066*** (0.019)	0.066*** (0.019)	0.066*** (0.019)
va			−0.045*** (0.011)	−0.067*** (0.011)	−0.069*** (0.011)	−0.071*** (0.011)	−0.066*** (0.011)	−0.066*** (0.011)
lnkemp				−0.025*** (0.003)	−0.016*** (0.005)	−0.033*** (0.007)	−0.033*** (0.007)	−0.033*** (0.007)
lnw					−0.016*** (0.007)	−0.035*** (0.017)	−0.035*** (0.017)	−0.039*** (0.018)
lnxl						0.043*** (0.011)	0.043*** (0.011)	0.042*** (0.012)
lnfdi							−0.000 (0.003)	0.001 (0.003)
open								−0.074** (0.034)
_cons	−0.035** (0.006)	−0.169*** (0.063)	−0.222*** (0.065)	−0.192*** (0.072)	−0.245*** (0.079)	−0.221*** (0.086)	−0.221** (0.086)	−0.198** (0.086)
N	240	240	240	240	240	240	240	240
R^2	0.096	0.104	0.149	0.284	0.292	0.360	0.360	0.377

Notes: *, **, and *** indicate significant levels at 10%, 5%, and 1%, respectively. Robust standard errors are reported in parentheses.

Table 4
Results of the 2SLS estimation.

	(1)	(2)	(3)
lner	0.021*	0.013***	0.014***
	(0.011)	(0.003)	(0.004)
lngopi	0.052*	0.097***	0.090***
	(0.028)	(0.021)	(0.023)
va	−0.063***	−0.105**	−0.105***
	(0.012)	(0.021)	(0.021)
lnkemp	−0.033***	−0.025***	−0.026***
	(0.007)	(0.006)	(0.007)
lnw	−0.039**	−0.076***	−0.077***
	(0.017)	(0.017)	(0.019)
lnxl	0.045***	0.059***	0.061***
	(0.013)	(0.011)	(0.012)
lnfdi	0.001	0.002	0.002
	(0.003)	(0.003)	(0.003)
open	−0.103**	−0.086***	−0.092***
	(0.047)	(0.031)	(0.033)
_cons	−0.128	−0.328***	−0.280***
	(0.121)	(0.101)	(0.114)
N	240	220	200
R^2	0.363	0.408	0.403
Kleibergen-Paap rk LM statistics	24.512 [0.000]	82.58 [0.000]	71.764 [0.000]
Kleibergen-Paap rk Wald F statistics	36.74 [16.38]	717.01 [16.38]	442.50 [16.38]
First stage results			
lnc	−0.346*** (0.057)		
L.lner		0.910*** (0.034)	
L2.lner			0.548***
			(0.208)
F-statistics	45.83	717.01	181.92

Notes: *, **, and *** indicate significant levels at 10%, 5%, and 1%, respectively.
Robust standard errors are reported in parentheses.

respectively. To test the validity of the instrumental variables, we use a variety of statistical tests. The first-stage regression results of the 2SLS method show that the coefficients of the instrumental variables are all significant at the 1% level, indicating that there are very strong correlations between the instrumental variables and the explanatory variables, and the large first-stage *F*-statistics implies that the instruments are strong. Moreover, the second-stage regression results show that both the Kleibergen-Paap rk LM statistics and the Kleibergen-Paap Wald rk F statistics rejected the null hypothesis that “instrument variables are insufficiently identified” and “instrument variables are weakly identified”. All the above conclusions indicate that the selected instrumental variables in this paper are reasonable. The regression results when considering the instrumental variable are reported in Table 4. Compared with the OLS regression results, we find that the estimated coefficients of environmental regulation have risen to a certain extent after the introduction of instrumental variables, indicating that the endogenous problem makes OLS results underestimate the role of environmental regulation in enhancing the position of GVCs.

The second robustness test is to add a panel data quantile regression. We now proceed to investigate whether the effect of environmental regulation varies by industry (industry heterogeneity). As we can see in Columns (1)–(5) of Table 5, the estimated coefficients of environmental regulation are all positive and statistically significant, and the coefficients are significantly larger at the 10th and 25th quantile, which indicates that environmental regulation has a more significant effect on industries with lower GVCs position. This is mainly because when the position of the GVCs is relatively low, the industry is at the downstream of the industrial chain and is more engaged in pollution-intensive work. In this context, environmental regulation will improve its production processes by stimulating innovation, which will effectively improve its GVCs position. When the position of GVCs of a sub-sector is high, it means that the sub-sector is already in the

Table 5
Results of panel data quantile regression.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	q (10)	q (25)	q (50)	q (75)	q (90)	GVCs_P	lnrca
lner	0.015** (0.006)	0.017*** (0.005)	0.010** (0.004)	0.011*** (0.003)	0.012***(0.004)	–	0.048***(0.018)
lner2	–	–	–	–	–	0.008**(0.003)	–
lngopi	0.120*** (0.036)	0.070*** (0.040)	0.048**(0.021)	0.033 (0.043)	−0.001 (0.055)	0.074***(0.020)	0.126***(0.140)
Va	−0.098*** (0.038)	−0.064*** (0.027)	−0.056** (0.024)	−0.065*** (0.021)	−0.072*** (0.029)	−0.066*** (0.011)	−0.067***(0.011)
lnkemp	−0.030 (0.026)	−0.040*(0.028)	−0.034***(0.011)	−0.035*** (0.011)	−0.050***(0.012)	−0.036***(0.007)	−0.018***(0.006)
lnw	−0.132*** (0.033)	−0.052 (0.036)	−0.009 (0.014)	−0.005 (0.019)	0.024 (0.026)	−0.042**(0.021)	−0.029**(0.016)
lnxl	0.112*** (0.020)	0.060***(0.020)	0.016 (0.018)	0.026**(0.012)	0.027***(0.009)	0.045***(0.013)	0.017 (0.011)
lnfdi	−0.007**(0.003)	−0.002 (0.005)	0.004 (0.005)	−0.002*** (0.002)	−0.005*** (0.002)	0.001 (0.003)	0.002 (0.003)
open	−0.104 (0.113)	−0.204* (0.111)	−0.035 (0.097)	−0.010 (0.024)	0.039 (0.043)	−0.056 (0.036)	−0.081***(0.031)
_cons	−0.543*** (0.155)	−0.234 (0.147)	−0.082 (0.099)	−0.022 (0.195)	0.137 (0.245)	−0.231***(0.088)	−0.483*** (0.080)
N	240	240	240	240	240	240	240
R^2	0.383	0.303	0.177	0.157	0.186	0.353	0.425

Notes: *, **, and *** indicate significant levels at 10%, 5%, and 1%, respectively. Robust standard errors are reported in parentheses. q (10)-q (90) represent the estimated results of the 10th, 25th, 50th, 75th, and 90th positions, respectively.

upstream of the value chain, the effect of environmental regulation on its GVCs position will be relatively weaker.

To further test the robustness of the results, we use the method of replacing the explanatory variables and explained variables. Firstly, we replace the measurement method of ER indicators, the industrial pollution abatement and control expenditure divided by the main industrial business costs is adopted to represent the intensity of environmental regulation, which is recorded as ER2. The regression results are shown in Column (6) of Table 5. The results indicate that after replacing the measurement method of ER indicators, the regression coefficient is still positive and statistically significant at the 5% critical level. Secondly, we replace the formerly explained variable (GVCs_P) with the RCA index. Based on the traditional calculation of the RCA index, this paper replaces the total export value with domestic value-added (DVA) and recalculates it according to the decomposition method of Koopman et al. (2014). (See Appendix B). Since international competitiveness is generally positively correlated with value appreciation, the value chain position can also be replaced by the RCA index (Koopman et al., 2010; Wang et al., 2013). The regression results are reported in Column (7) of Table 5. The regression coefficient is still positive and statistically significant at the 1% critical level, indicating that environmental regulation has indeed effectively increased the industry's international competitiveness, which well proves the robustness of the results in this paper.

4.2.3. Impacting mechanism analysis

To explore the channels through which environmental regulation affects the GVCs position of China's industrial sector, we conduct an empirical analysis from two aspects including research and development expenditure and proportion of domestic intermediate products using the mediating effect model shown as follows:

$$\mathrm{GVCs\_P}_{it} = a_0 + a_1 \mathrm{lner}_{it} + \sum_{j=2} a_j \mathrm{control}_{jt} + \varepsilon_{it} \tag{4}$$

$$\mathrm{M}_{it} = b_0 + b_1 \mathrm{lner}_{it} + \sum_{j=2} b_j \mathrm{control}_{jt} + \varepsilon_{it} \quad \mathrm{M}_{it} = \mathrm{rd}_{it} \ \text{ or } \ \mathrm{df}_{it} \tag{5}$$

$$\mathrm{GVCs\_P}_{it} = c_0 + c_1 \mathrm{lner}_{it} + c_2 \mathrm{M}_{it} + \sum_{j=3} c_j \mathrm{control}_{jt} + \varepsilon_{it} \quad \mathrm{M}_{it} = \mathrm{rd}_{it} \ \text{ or } \ \mathrm{df}_{it} \tag{6}$$

According to the theoretical analysis shown above, on the one hand, environmental regulation may encourage enterprises to innovate to enhance the GVCs position. On the other hand, environmental regulation may also lead to the transfer of production links to areas with relatively weak environmental regulation, and replace them by importing intermediate products from other countries, which may further reduce its position in the GVCs. In this paper, the logarithm of internal expenditures for industry scientific and technological activities is selected as the intensity of research and development (rd) to verify the former path, and the ratio of domestic intermediate product input to foreign intermediate product input is adopted as the proportion of domestic intermediate products (df), to determine whether environmental regulation has caused the transfer of the industrial chain.

Column (1) of Table 6 reports the result of Eq. (4), which is the same as the benchmark regression. Columns (2) and (4) are the results for research and development expenditure and Columns (3) and (5) are the results for the proportion of domestic intermediate products, respectively. Combined with Columns (2) and (4), we find that environmental regulation can significantly improve the intensity of research and development expenditure in China's industrial sector. In addition, compared with the benchmark regression results, after adding the mediating variable, the estimated coefficient of environmental regulation declined, which indicates the existence of the mediating effect of R&D innovation incentives (Wen and Ye, 2014), and it well confirms the existence of the Porter hypothesis. In contrast, as we can see in Column (3), the regression coefficient of environmental regulation on the proportion of domestic intermediate products is not statistically significant, indicating that environmental regulation has not caused the transfer of production links in this industry, which indicates that

Table 6
Results of mechanism inspection.

	(1)	(2)	(3)	(4)	(5)
	GVCs_P	rd	Df	GVCs_P	
lner	0.014*** (0.003)	0.004*** (0.002)	0.193 (0.150)	0.013*** (0.003)	0.012*** (0.003)
rd	–	–	–	0.171*** (0.054)	–
df	–	–	–	–	0.008*** (0.001)
lngopi	0.066*** (0.019)	−0.012** (0.009)	5.028*** (0.749)	0.068*** (0.019)	0.028 (0.017)
va	−0.066*** (0.011)	0.008* (0.004)	−0.006 (0.004)	−0.067*** (0.011)	−0.001*** (0.000)
lnkemp	−0.033*** (0.007)	−0.002*** (0.001)	−0.288 (0.234)	−0.032*** (0.007)	−0.030*** (0.007)
lnw	−0.039*** (0.018)	0.003 (0.003)	−1.256** (0.464)	−0.039** (0.018)	−0.030** (0.015)
lnxl	0.042*** (0.012)	0.006 (0.002)	0.627 (0.339)	0.041*** (0.012)	0.038*** (0.011)
lnfdi	0.001 (0.003)	0.001 (0.001)	−0.420*** (0.138)	0.001 (0.003)	0.004 (0.003)
open	−0.074** (0.033)	−0.022 (0.016)	−5.500*** (1.418)	−0.071** (0.034)	−0.032 (0.034)
_cons	−0.198** (0.086)	0.067 (0.048)	−0.420** (0.138)	−0.209** (0.087)	−0.095 (0.073)
N	240	240	240	240	240
R^2	0.3771	0.0386	0.1850	0.3813	00.4707

Notes: *, **, and *** indicate significant levels at 10%, 5%, and 1%, respectively. Robust standard errors are reported in parentheses.

Table 7
Results of the heterogeneous on GVCs positions.

	(1)	(2)	(3)	(4)
lner	−0.002***(0.001)	−0.001***(0.000)	−0.018**(0.002)	−0.007**(0.003)
lngopi		−0.004 (0.003)		−0.078***(0.021)
va		−0.001 (0.000)		0.070*** (0.011)
lnkemp		−0.012***(0.001)		0.023***(0.007)
lnw		0.002 (0.001)		0.040** (0.019)
lnxl		0.015***(0.001)		−0.029**(0.012)
lnfdi		0.000 (0.000)		−0.001 (0.003)
_cons	0.058***(0.002)	0.049***(0.014)	0.093*** (0.006)	0.299***(0.093)
N	240	240	240	240
R^2	0.048	0.432	0.120	0.311

Notes: *, **, and *** indicate significant levels at 10%, 5%, and 1%, respectively.
Robust standard errors are reported in parentheses.

the pollution haven hypothesis does not exist to some extent.

We further study the heterogeneous impact of environmental regulation on the forward and backward GVCs positions, and the results are reported in Table 7. Columns (1) and (2) are the regression results for forward GVCs position, and Columns (3) and (4) are the regression results for the backward GVCs position. It can be seen that all the regression coefficients are negative, either for the forward or the backward GVCs position.

As described in Section 2 of this paper, environmental regulation reduces the backward GVCs position by encouraging enterprises to innovate, constantly improving their capacity for independent innovation, and using domestic intermediate products to replace foreign products in final products. The underlying reason why the regression coefficient of forward GVCs position is negative may be that the primary products originally used for export are shifted to domestic sales due to domestic demand for intermediate production (Kee and Tang, 2016). Meanwhile, comparing the coefficients of forward and backward GVCs positions, we find that the absolute value of the regression coefficient for the backward GVCs position is obviously greater than that for the forward GVCs position, which indicates that the influence of environmental regulation on the GVCs position of China's industrial sector is mainly achieved by reducing the backward GVCs position.

5. Conclusion and policy implications

Based on the latest value-added decomposition method, we measure the GVCs position of China's industrial sector from 2003 to 2014. Subsequently, the impact of environmental regulation on the GVCs position of China's industrial sector is further empirically studied. We find the following results: first, environmental regulation significantly enhances the position of GVCs. After using the two-stage least squares (2SLS) method to treat the endogenous problem, the results still stand. Second, the results of panel data quantile regression show that environmental regulation has imposed a heterogeneous impact on their GVCs position, and the lower the GVCs position of a sub-sector, the more significant the improvement effect. Third, mediation effect analysis indicates that innovation incentive is an important channel to effectively enhance the GVCs position of China's industrial sector, which proves the existence of the Porter hypothesis. Last but not the least, environmental regulation could effectively reduce the backward GVCs position, so as to enhance the overall GVCs position of China's industrial sector, but the effect of environmental regulation on the forward GVCs position is minor.

According to the conclusions drawn above, we can put forward some useful recommendations: first, this paper verifies the existence of the Porter hypothesis, that is, environmental regulation could effectively enhance the GVCs position of China's industrial sector by stimulating enterprise innovation, especially for those industries with lower GVCs position. Therefore, the Chinese government should continue to implement more environmental regulation policies and innovation-driven development strategies, so as to fight for the upstream position of the global industrial chain. Second, although the GVCs position of China's industrial sector has been increasing, the position of forward GVCs has not changed significantly, implying that the international competitiveness of China's intermediate products in various industries is still insufficient. Therefore, the Chinese government should improve the production capacity of intermediate products, especially for the core intermediate products with high technological content.

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Appendix A. Industries covered by this paper

Appendix B. RCA index measurement method and results:

The concept of revealed comparative advantage (RCA), proposed by Balassa (1965) has proven to be useful in many research and policy applications (Koopman, 2014). In standard applications, it is defined as the share of a sector in a country's total gross exports relative to the world average of the same sector in world exports. The RCA formula behaves as follows:

$$RCA_r^i = \frac{e_r^i \Big/ \sum_i^n e_r^i}{\sum_r^m e_r^i \Big/ \sum_r^m \sum_i^n e_r^i}$$

According to the measurement method of Koopman (2014), this paper replaces total gross exports with domestic value added (DVA), that is, the sum of the top five items in Table 1 of the text. When the RCA index is greater than 1, it indicates that the export of this industry in this country has a clear comparative advantage; when the RCA index is less than 1, it indicates that the export of this sector in the country has a significant comparative disadvantage. The following table is the RCA index of China's industrial sector:

Table A1
Industries being merged

Industries	ISICRev-4	Industries in China Statistical Yearbooks
S1	Mining and quarrying	(1)+(2)+(3)+(4)+(5)
S2	Food products, beverages and tobacco products	(6)+(7)+(8)+(9)
S3	Textiles, wearing apparel and leather products	(10)+(11)+(12)
S4	Wood and products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials	(13)
S5	Paper and paper products	(14)
S6	Printing and reproduction of recorded media	(15)
S7	Coke and refined petroleum products	(16)
S8	Chemicals and chemical products	(17)+(18)
S9	Basic pharmaceutical products and pharmaceutical preparations	(19)
S10	Rubber and plastic products	(20)
S11	Other non-metallic mineral products	(21)
S12	Basic metals	(22)+(23)
S13	Fabricated metal products, except machinery and equipment	(24)
S14	Computer, electronic and optical products	(25)+(26)
S15	Electrical equipment	(27)
S16	Machinery and equipment n.e.c.	(28)+(29)
S17	Transport equipment	(30)+(31)
S18	Manufacture of furniture; other manufacturing	(32)+(33)
S19	Electricity, gas, steam and air conditioning supply	(34)+(35)
S20	Water collection, treatment and supply	(36)

Notes: (1): Coal mining and washing; (2): Oil and gas mining; (3): Ferrous metal mining; (4): Non-ferrous metal mining; (5): Non-metallic mining; (6): Agricultural and sideline food processing industry; (7): Food manufacturing; (8): Beverage manufacturing; (9): Tobacco manufacturing; (10): Textiles; (11): Textile clothing, clothing industry; (12): Leather, fur, feather and their products; (17): Chemical raw materials and chemical products manufacturing; (18): Chemical fiber manufacturing; (22): Ferrous metal smelting; (23): Non-ferrous metal smelting; (25): Computer, communication and other electronic equipment manufacturing; (26): Instrument manufacturing industry; (28): General equipment manufacturing; (29): Special equipment manufacturing; (30): Motor industry; (31): Other transport equipment; (32): Furniture manufacturing; (33): Culture and education, industrial beauty, sports and entertainment manufacturing; (34) Production and supply industry of electricity and heating; (35): Gas production and supply.

Table B1
RCA index of China's industrial sector

RCA	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
S1	0.9248	0.8115	0.7290	0.6533	0.6102	0.6362	0.6033	0.5550	0.5289	0.4802	0.5411	0.6063
S2	1.0557	1.0931	1.1738	1.1894	1.1775	1.1723	1.0758	1.1128	1.1334	1.1820	1.1352	1.0906
S3	3.1936	3.2384	3.3940	3.3965	3.3801	3.2994	3.2331	3.1583	3.1184	3.0375	2.9305	2.7727
S4	1.4992	1.6886	1.6778	1.8921	1.9498	1.9365	2.1736	1.8130	1.9825	2.1404	2.1289	2.0180
S5	1.0287	1.0136	0.9620	0.9942	0.9865	1.0296	1.0479	0.9877	1.0536	1.0997	1.0449	1.0217
S6	1.4457	1.2778	1.0652	1.0430	0.9624	0.9923	1.1258	1.1149	1.1753	1.3032	1.3082	1.2762
S7	1.1380	1.1850	1.1208	1.1454	1.2683	1.2389	1.2801	1.5010	1.1994	1.1163	1.1396	1.1294
S8	1.2650	1.2330	1.3372	1.3554	1.3761	1.4909	1.2654	1.2244	1.3277	1.2494	1.2070	1.1901
S9	0.3131	0.3081	0.3037	0.3177	0.3417	0.3520	0.3004	0.3262	0.3133	0.3301	0.3413	0.3232
S10	1.5984	1.5849	1.4887	1.5045	1.4265	1.4393	1.3771	1.3398	1.3716	1.3851	1.3726	1.3206
S11	1.3655	1.4041	1.4894	1.5396	1.5139	1.6005	1.7283	1.7029	1.8546	1.9501	2.0179	1.8839
S12	1.8900	1.9405	1.8752	1.8503	1.8091	2.0302	1.8470	1.7668	1.7604	1.6412	1.5593	1.5563
S13	0.7430	0.8213	0.8348	0.8872	0.9341	0.9244	0.9498	0.8840	0.8875	0.9616	0.9490	0.9165
S14	1.5277	1.6946	1.6810	1.7211	1.6779	1.6788	1.6918	1.8618	1.8447	1.8658	1.8474	1.7757
S15	1.4712	1.4978	1.6015	1.5333	1.5426	1.6883	1.5622	1.7585	1.8171	1.8729	1.8294	1.8097
S16	1.0013	1.0538	1.0010	1.0915	1.2510	1.2982	1.3254	1.2768	1.2922	1.1820	1.1982	1.1639
S17	0.4744	0.4769	0.4709	0.5014	0.5734	0.6406	0.6668	0.7857	0.7710	0.7139	0.6797	0.6406
S18	1.9442	1.5983	2.0304	2.1712	2.1113	1.8239	1.7089	1.2842	1.3455	1.6173	1.5630	1.5108
S19	1.2852	1.3655	1.3354	1.3151	1.3189	1.0281	0.9693	0.9465	0.9274	0.8878	0.9500	0.9939
S20	0.8767	0.8842	0.8456	0.8393	0.8305	0.6065	0.5836	0.4948	0.4332	0.4109	0.4413	0.4838

References

Balassa, B., 1965. Trade liberalisation and "revealed" comparative advantage. Manch. Sch. 33 (2), 99–123. https://doi.org/10.1111/j.1467-9957.1965.tb00050.x.

Borsatto, J.M.L.S., Amui, L.B.L., 2019. Green innovation: unfolding the relation with environmental regulations and competitiveness. Resour. Conserv. Recycl. 149, 445–454. https://doi.org/10.1016/j.resconrec.2019.06.005.

Brandi, C., Schwab, J., Berger, A., et al., 2020. Do environmental provisions in trade agreements make exports from developing countries greener? World Dev. 129, 104899. https://doi.org/10.1016/j.worlddev.2020.104899.

Cole, M.A., Elliott, R.J.R., 2003a. Determining the trade-environment composition effect: the role of capital, labor and environment regulations. J. Environ. Econ. Manag. 46 (3), 363–383. https://doi.org/10.1016/S0095-0696(03)00021-4.

Cole, M.A., Elliott, R.J.R., 2003b. Do environmental regulations influence trade patterns? Testing old and new trade theories. World Econ. 26 (8), 1163–1186. https://doi.org/10.1111/1467-9701.00567.

Cui, J.B., Moschini, G.C., 2020. Firm internal network, environmental regulation, and plant death. J. Environ. Econ. Manag. 101, 102319. https://doi.org/10.1016/j.jeem.2020.102319.

Du, W.J., Li, M.J., 2019. Can environmental regulation promote the governance of excess capacity in China's energy sector? The market exit of zombie enterprises. J. Clean. Prod. 207, 306–316. https://doi.org/10.1016/j.jclepro.2018.09.267.

Fu, J.Y., Li, L.S., 2010. A case study on the environmental regulation, the factor endowment and the international competitiveness in industries. Manag. World 10, 87–98. https://doi.org/10.19744/j.cnki.11-1235/f.2010.10.008 (**In Chinese**).

Ghani, G.M., 2012. Does trade liberalization effect energy consumption? Energy Pol. 43, 285–290. https://doi.org/10.1016/j.enpol.2012.01.005.

He, J., 2006. Pollution haven hypothesis and environmental impacts of foreign direct investment: the case of industrial emission of sulfur dioxide (SO_2) in Chinese provinces. Ecol. Econ. 60 (1), 228–245. https://doi.org/10.1016/j.ecolecon.2005.12.008.

Hummels, D., Ishii, J., Yi, K.M., 2001. The nature and growth of vertical specialization in world trade. J. Int. Econ. 54 (1), 75–96. https://doi.org/10.1016/S0022-1996(00)00093-3.

Hye, Q.M.A., Wizarat, S., Lau, W.Y., 2016. The impact of trade openness on economic growth in China: an empirical analysis. The Journal of Asian Finance, Economics and Business 3 (3), 28–38. https://doi.org/10.13106/jafeb.2016.vol3.no3.27.

Hwang, J.A., Kim, Y., 2017. Effects of environmental regulations on trade flow in manufacturing sectors: comparison of static and dynamic effects of environmental regulations. Bus. Strat. Environ. 26 (5), 688–706. https://doi.org/10.1002/bse.1965.

Jakubik A, Stolzenburg V. The "China shock" revisited: insights from value added trade flows. WTO Staff Working Papers ERSD-2018-10. doi:10.30875/cbf82acd-en.

Kee, H.L., Tang, H.W., 2016. Domestic value added in exports: theory and firm evidence from China. Am. Econ. Rev. 106 (6), 1402–1436. https://doi.org/10.1257/aer.20131687.

Koopman, R., Powers, W., Wang, Z., Wei, S.J., 2010. Give Credit where Credit Is Due: Tracing Value Added in Global Production Chains. NBER Working Papers 16426.

Koopman, R., Wang, Z., Wei, S.-J., 2014. Tracing value-added and double counting in gross exports. Am. Econ. Rev. 104 (2), 459–494. https://doi.org/10.1257/aer.104.2.459.

Lanoie, P., Laurent, L., Johnstone, N., et al., 2011. Environmental policy, innovation and performance: new insights on the Porter hypothesis. J. Econ. Manag. Strat. 20, 803–842. https://doi.org/10.1111/j.1530-9134.2011.00301.x.

LaPlue, L.D., 2019. The environmental effects of trade within and across sectors. J. Environ. Econ. Manag. 94, 118–139. https://doi.org/10.1016/j.jeem.2019.01.007.

Larson, B.A., Nicolaides, E., Al Zu'bi, B., et al., 2002. The impact of environmental regulations on exports: case study results from Cyprus, Jordan, Morocco, Syria, Tunisia, and Turkey. World Dev. 30 (6), 1057–1072. https://doi.org/10.1016/S0305-750X(02)00023-2.

Leontief, W.W., 1936. Quantitative input and output relations in the economic systems of the United States. Rev. Econ. Stat. 18 (3), 105–125. https://doi.org/10.2307/1927837.

Levinson, A., Taylor, M.S., 2008. Unmasking the pollution haven effect. Int. Econ. Rev. 49 (1), 223–254. https://doi.org/10.1111/j.1468-2354.2008.00478.x.

Liu, H., Li, J., Long, H., et al., 2018. Promoting energy and environmental efficiency within a positive feedback loop: insights from global value chain. Energy Pol. 121, 175–184. https://doi.org/10.1016/j.enpol.2018.06.024.

Ouyang, X., Li, Q., Du, K., 2020. How does environmental regulation promote technological innovations in the industrial sector? Evidence from Chinese provincial panel data. Energy Pol. 139, 111310. https://doi.org/10.1016/j.enpol.2020.111310.

Qiu, L.D., Zhou, M., Wei, X., 2018. Regulation, innovation, and firm selection: the porter hypothesis under monopolistic competition. J. Environ. Econ. Manag. 92, 638–658. https://doi.org/10.1016/j.jeem.2017.08.012.

Rubashkina, Y., Galeotti, M., Verdolini, E., 2015. Environmental regulation and competitiveness: empirical evidence on the Porter Hypothesis from European manufacturing sectors. Energy Pol. 83, 288–300. https://doi.org/10.1016/j.enpol.2015.02.014.

Sun, C., Li, Z., Ma, T., He, R., 2019a. Carbon efficiency and international specialization position: evidence from global value chain position index of manufacture. Energy Pol. 128, 235–242. https://doi.org/10.1016/j.enpol.2018.12.058.

Sun, H., Edziah, B.K., Sun, C., Kporsu, A.K., 2019b. Institutional quality, green innovation and energy efficiency. Energy Pol. 135, 111002. https://doi.org/10.1016/j.enpol.2019.111002.

Sun, H., Kporsu, A.K., Taghizadeh-Hesary, F., et al., 2020. Estimating environmental efficiency and convergence: 1980 to 2016. Energy 208, 118224. https://doi.org/10.1016/j.energy.2020.118224.

Sheng, B., Jing, G.Z., 2019. Financial structure, contractual environment and global value chain position. The Journal of World Economy 42 (4), 29–52 (**In Chinese**).

Shi, X.Z., Xu, Z.F., 2018. Environmental regulation and firm exports: evidence from the eleventh five-year plan in China. J. Environ. Econ. Manag. 89, 187–200. https://doi.org/10.1016/j.jeem.2018.03.003.

Testa, F., Iraldo, F., Frey, M., 2011. The effect of environmental regulation on firms' competitive performance: the case of the building & construction sector in some EU regions. J. Environ. Manag. 92 (9), 2136–2144. https://doi.org/10.1016/j.jenvman.2011.03.039.

Timmer, M.P., Dietzenbacher, E., Los, B., et al., 2015. An illustrated user guide to the world input-output database: the case of global automotive production. Rev. Int. Econ. 23, 575–605. https://doi.org/10.1111/roie.12178.

Wang, J., Duan, R.Z., Sun, X.M., 2019. Environmental regulation, product quality and Chinese firms' upgrading in global value chain. Ind. Econ. Res. 99 (2), 64–75. https://doi.org/10.13269/j.cnki.ier.2019.02.006 (**In Chinese**).

Wang, C.H., Wu, J.J., Zhang, B., 2018. Environmental regulation, emissions and productivity: evidence from Chinese COD-emitting manufacturers. J. Environ. Econ. Manag. 92, 54–73. https://doi.org/10.1016/j.jeem.2018.08.004.

Wang, Z., Wei, S.J., Yu, X.D., Zhu, K.F., 2013. Quantifying international production sharing at the bilateral and sector levels. NBER Working Papers 19677. https://doi.org/10.13140/2.1.2544.7681.

Wang, Z., Wei, S.J., Yu, X.D., Zhu, K.F., 2017. Characterizing Global Value Chains: Production Length and Upstreamness. https://doi.org/10.3386/w23261. NBER Working Paper 23261.

Wang, Z.H., Zhang, B., Zeng, H.L., 2015. The effect of environmental regulation on external trade: empirical evidences from Chinese economy. J. Clean. Prod. 114 (2), 55–61. https://doi.org/10.1016/j.jclepro.2015.07.148.

Wen, Z.L., Ye, B.J., 2014. Analyses of mediating effects: the development of methods and models. Adv. Psychol. Sci. 22 (5), 731–745. https://doi.org/10.3724/SP.J.1042.2014.00731.

Xie, B., Jia, X., Yi, Z.H., 2018. The influence of environmental regulation on the global value chain of services-An empirical study based on panel data of 45 OECD countries. Modern Economic Research 5, 70–77. https://doi.org/10.13891/j.cnki.mer.2018.05.010 (**In Chinese**).

Xu, D.L., Zhang, M., 2020. Impact of environmental regulation on the upgrading of global value chain: promoting or inhibiting? J. China Univ. Geosci. 20 (3), 75–89. https://doi.org/10.16493/j.cnki.42-1627/c.2020.03.007 (**In Chinese**).

Yu, C.J., Luo, Z.H., 2018. What are China's real gains within global value chains? Measuring domestic value added in China's exports of manufactures. China Econ. Rev. 47, 263–273. https://doi.org/10.1016/j.chieco.2017.08.010.

Zhao, X.M., Liu, C.J., Yang, M., 2018. The effects of environmental regulation on China's total factor productivity: an empirical study of carbon-intensive industries. J. Clean. Prod. 179 (4), 325–334. https://doi.org/10.1016/j.jclepro.2018.01.100.