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Impact of global value chain embedding on industrial environmental performance: An empirical study based on the countries along the "Belt and Road"

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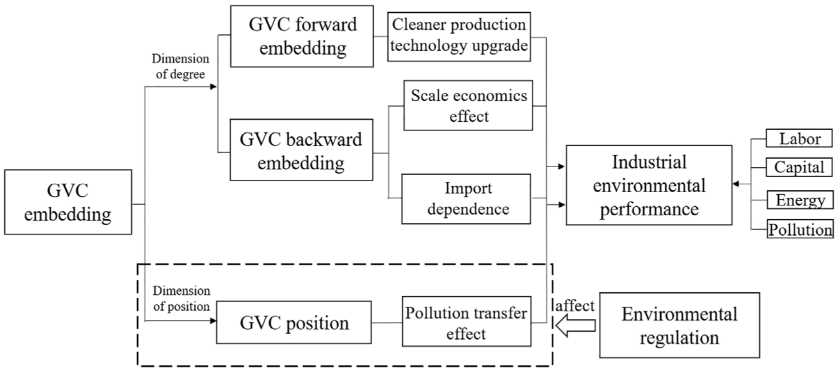
Global value chain (GVC) embedding is a "Double-edged sword". While the countries along the "Belt and Road" benefit from the dividends brought by GVC embedding, the environmental pollution caused by industrial production becomes increasingly severe due to the lack of core technology and weak research and development (R&D) capability. Environmental performance can comprehensively reflect the cleaner production level of the industry considering the interaction of various input factors. With the deepening of GVC embedding in countries along the "Belt and Road", it is essential to improve industrial environmental performance from the perspective of GVC embedding. Based on the industrial sector data from 15 countries along the "Belt and Road" during the period from 2007 to 2020, the impacts of GVC embedding on industrial environmental performance are empirically examined in this study using the feasible generalized least squares (FGLS) and panel threshold model. The findings of this study could shed light on industrial pollution emission reduction measures through GVC embedding for the "Belt and Road" countries. Specifically, the results manifest that: 1) The increase of GVC forward embedding promotes industrial environmental performance, while the increase of GVC backward embedding has an inhibitory effect. 2) The impact of GVC position on industrial environmental performance shows a evident threshold effect with respect to the intensity of environmental regulation. In other words, when a country's environmental regulation intensity rises continuously and crosses the threshold value, the upgrade of the GVC position will promote industrial environmental performance. 3) The effect of GVC embedding on industrial environmental performance is heterogeneous. From the perspective of cross-border times of added value, GVC backward simple embedding inhibits industrial environmental performance, while GVC backward complex embedding is promotive. From the perspective of time heterogeneity, the implementation of the "Belt and Road" Initiative has changed the impact of GVC backward embedding on environmental performance from inhibition to promotion. In the end, this paper provides policy implications for countries along the "Belt and Road" to establish a green and low-carbon circular development system and achieve the goal of industrial clean production.

KEYWORDS

global value chain, environmental performance, industry, embedding degree, embedding position



GRAPHICAL ABSTRACT

1 Introduction

With the deepening of economic globalization, the form of international division of labor has changed radically. It has evolved from the division of labor between industries based on comparative advantages to the current division of labor in the global value chain (GVC) (Koopman et al., 2012). For a long time, most countries along the "Belt and Road" have participated in the GVC division of labor by taking advantage of labor and resource endowment. However, due to the lack of core technology and capability in research and development, the industries of the "Belt and Road" countries have been locked in the low-end links of GVC with low added value, followed by a serious pollution emission problem (Cai et al., 2018; Shi et al., 2022). According to the statistics of the International Energy Agency, the industrial carbon emissions of countries along the "Belt and Road" accounted for about 75% of the global total amount in 2019. Facing the huge pressure of pollution control, improving the cleaner production level is the sole solution for the industrial industry to achieve the dual goals of pollution reduction and economic growth (Merli et al., 2018).

Environmental performance is a comprehensive reflection of the cleaner production level of industry considering the interaction of various input factors (Liu et al., 2015). With the gradual deepening of GVC embedding and the increasingly severe industrial environmental pollution in the "Belt and Road" members, it is urgent to improve industrial environmental performance from the perspective of GVC embedding. The environmental effects of GVC embedding have been widely analyzed, but different conclusions have been reached. First, some scholars found that GVC embedding could improve environmental performance (Liu et al., 2018; Shi et al., 2021), which is more evident for developing countries (Sun et al., 2019). It is also pointed out that financial assistance and technology level influence the promotion effect of GVC embedding on environmental performance (Achabou et al., 2017); Secondly, some scholars found that GVC embeddedness inhibited environmental performance (Fei et al., 2020; Wang and Chen, 2022). This is because GVC embedding exacerbates the pollution transfer effect. Developed countries can transfer highly polluting enterprises to developing countries through GVC, which hinders their environmental performance improvement (Duan et al., 2021). China has undertaken the most pollution transfer of final products under the background of GVC embedding (Zhang and Wang, 2021). Finally, some scholars have found that the effect of GVC embedding on environmental performance shows an inverted U-shaped trend. Only when high production technology level and GVC embedding position are ensured, will GVC embedding promote environmental performance (Wang et al., 2019; Wang et al., 2021; Zheng et al., 2022). It can be seen that numerous analyses on the environmental effects of GVC embedding have been conducted. However, there are few literatures that systematically distinguish GVC embedding by value-added flow and cross-border frequency simultaneously, and comprehensively discuss the impact of GVC embedding of different embedding directions and complexity on environmental performance in combination with the change of environmental regulation intensity. A comprehensive analysis of the impact of GVC embedding on environmental performance based on different environmental regulatory intensities can provide a deeper understanding of the role of GVC embedding in pollution emissions and economic structural transformation.

Specifically, the 2007–2020 Asian Development Bank Regional Input-Output Tables are used in this study to empirically analyze the impact of GVC embedding of different embedding directions and complexity on the industrial environmental performance of countries along the “Belt and Road”. The threshold effect of the environmental regulation intensity on the GVC embedding impact is further investigated. Based on the actual development of the industrial sector, this study mainly answers the following questions: What is the effect of GVC embedding with different embedding directions and complexity on industrial environmental performance? With the variations of the environmental regulation level among countries, will the impact of GVC embedding on industrial environmental performance change? Scientific answers to these questions contribute to weighing and coordinating the economic benefits and environmental costs of the “Belt and Road” countries that embed GVC. Policy implications can then be provided to establish a green industrial circular development system and achieve the goal of industrial cleaner production.

Compared with the existing studies, the marginal contributions of this paper are as follows: Regarding the research perspective, this paper uses multinational panel data to construct an analytical framework for GVC embedding on the industrial environmental performance of countries along the “Belt and Road” from the dual dimensions of embedding direction and embedding complexity. Environmental regulation indicators are further incorporated into the analysis framework to explore the threshold effect of environmental regulation on the GVC embedding impact on environmental performance and clarify how the environmental effect of GVC embedding changes under different environmental regulation intensities. In terms of research methods, the super-efficiency SBM-DEA model is introduced to measure industrial environmental performance. This measurement method, which avoids the problem of ineffective relaxation variables, can reflect the actual production process effectively. Besides, the experience basis for cleaner production and core competitiveness improvement of industrial sectors along the “Belt and Road” from the perspective of GVC embedding could be provided.

The rest of this paper is arranged as follows: The literature review is given in Section 2, while in Section 3, the impact mechanism of the GVC embedding on industrial environmental performance is analyzed and corresponding hypotheses are proposed. Section 4 presents the model setting, measurement method and data description. Afterward, empirical tests are carried out in Section 5 and Section 6 to verify the proposed hypotheses. Section 7 is wrapped up with the conclusions and policy implications.

2 Literature review

The existing researches on environmental performance mainly focus on two aspects, the measurement method and the influencing factors. Environmental performance can be evaluated by single-factor and total-factor methods according to different definition frameworks. Single-factor environmental performance method is performed by adopting the ratio of pollution emissions to economic variables (such as GDP and energy consumption) as an indicator (Kaya and Yokobori, 1998; Mielnik and Goldemberg, 1999; Du et al., 2017). Although it has the characteristics of being intuitive and easy to use, it cannot reflect the gap between the actual pollution discharge of the decision-making unit and the discharge when the optimal production is achieved. Total-factor environmental performance evaluation methods mainly include parametric and non-parametric estimation methods. In the parameter estimation method, the parameter form is used to describe the directional distance function (Vardanyan and Noh, 2005; Park and Lim, 2009). For example, Fare et al. (2005) used a quadratic function to identify the directional distance function, and transformed it into an estimable equation. However, due to the difficulty of model identification in parametric methods, the DEA method based on non-parametric estimation is mostly employed to measure environmental performance (Xiong et al., 2022; Yu et al., 2022). For traditional DEA models such as CCR and BCC, only radial improvements are considered, while slack improvements are ignored when evaluating efficiency scores. In view of the shortcomings of traditional DEA models, Tone (2001) proposed a DEA model based on slack measurement, namely the SBM-DEA model, which solved the slack problem of input and output in environmental performance assessment and was more in line with the production needs of decision makers. Based on the research of Tone (2001), this study adopts the super-efficiency SBM-DEA model to evaluate the environmental performance.

Regarding the factors affecting environmental performance, government regulation (Zhang et al., 2022), internet development (Wu et al., 2021; Ren et al., 2022), technological innovation (Xu et al., 2021), energy efficiency (Yang et al., 2021), land use (Jia et al., 2022), governance structure (Nguyen et al., 2021), and etc. have been analyzed. In the context of the continuous development of the “Belt and Road” initiative, it is found that the “Belt and Road” initiative can narrow the environmental performance gap between countries through trade integration and regional cooperation (Han et al., 2018). China’s foreign direct investments promote the environmental performance of countries along the “Belt and Road”, while the large institutional differences among countries inhibit the improvement of environmental performance (Xie and Zhang, 2021). At this stage, the environmental performance of the "Belt and Road" members is generally low, and the pollution emission problem is severe (Wei et al., 2020). Scholars also paid attention to the impact of environmental regulation policies on environmental performance and found that the long-term implementation of environmental regulation can promote enterprises to increase research and development investment, improve the level of clean production technology, reduce pollution emissions, and further promote the environmental performance of the "Belt and Road" countries (Cai et al., 2018; Wu and Lin, 2022).

With the GVC division of labor mode becoming the new normal of the international division of labor system, there are increasing scholars studying environmental performance from the perspective of GVC embedding. The effects of GVC embedment degree, embedment position and production chain length on environmental performance are mainly investigated. From the perspective of GVC embedding degree, it is found that GVC embedding can enhance industrial green technology innovation and improve clean production technology (Hu et al., 2022), thus reducing manufacturing pollution emissions (Shi et al., 2021; Ma et al., 2022). Compared with developed countries, GVC embedding in developing countries has a greater negative impact on pollution emissions (Liu and Zhao, 2020). Further research found that, compared with traditional trade, the pollution emissions in GVC activities are more concealed, and the deepening of GVC embeddedness has an inverted U-shaped impact of "first promotion, then inhibition" on pollution emission. Only when high GVC embeddedness is reached, can it promote environmental performance (Jing et al., 2019; Wang et al., 2021). From the perspective of GVC embedding position, it is found that the improvement of GVC position can reduce pollution emissions and improve environmental performance through scale and structure effects (Shi et al., 2022). However, developed countries with higher GVC position will transfer pollution to developing countries with lower GVC position through international division of labor, which will inhibit their environmental performance (Zheng, 2021; Pan et al., 2022). Moreover, with the improvement of GVC embedding position, the environmental performance of enterprises decreases first and then increases. Through the analysis of industry heterogeneity, it is found that technology-intensive enterprises are more likely to break through the critical point of environmental performance reduction (Zheng et al., 2022). From the perspective of GVC production length, it is found that the total average production length of GVC and environmental performance show a U-shaped relationship of "first inhibition, then promotion", and China has surmounted its critical point (Wang et al., 2020). Increasing the length of the GVC forward production chain can effectively reduce the pollution emissions of labor-intensive and technology-intensive industries, but it has no significant impact on the environmental performance of capital-intensive sectors (Chen et al., 2022).

To sum up, the impact of GVC embedding on environmental performance has been studied from the perspective of GVC embedding degree, embedding position, and production length. Different research conclusions have been reached due to differences in countries and industries. However, there still lacks research on the relationship between GVC embedding and environmental performance with different embedding directions and embedding complexity. In addition, the heterogeneous impact of GVC embedding on environmental performance as the intensity of environmental regulation changes has been scarcely explored. Therefore, this paper analyzes the impact of GVC embedding on the industrial environmental performance from the dual dimensions of embedding direction and embedding complexity. The threshold effect of the environmental regulation intensity on the GVC embedding impact is further investigated, which provides a theoretical basis and policy support for countries along the "Belt and Road" to weigh and coordinate the economic benefits and environmental costs of participating in GVC.

3 Mechanism analysis of the influence of global value chain embedding on industrial environmental performance

3.1 Analysis on the promotion effect of global value chain forward embedding on environmental performance

The increase of GVC forward embedding will promote the upgrading of industrial cleaner production technology in the "Belt and Road" members, which promote environmental performance through export reverse forcing effect, competition effect, and technology spillover effect. Figure 1 is the mechanism diagram of the promotion effect of GVC forward embedding on environmental performance.

First of all, the increase of GVC forward embedding will bring about the export reverse forcing effect. Since most countries along the "Belt and Road" are developing countries, when their GVC forward participation and the export of industrial intermediate products increases, the stricter environmental protection standards and energy use requirements of developed countries will force the industrial export enterprises to carry out cleaner production technology innovation (Song et al., 2020). To meet the requirements of developed countries on environmental protection and quality of imported industrial products, developing countries will actively introduce advanced cleaner production technologies to improve the environmental protection standards of exported products.

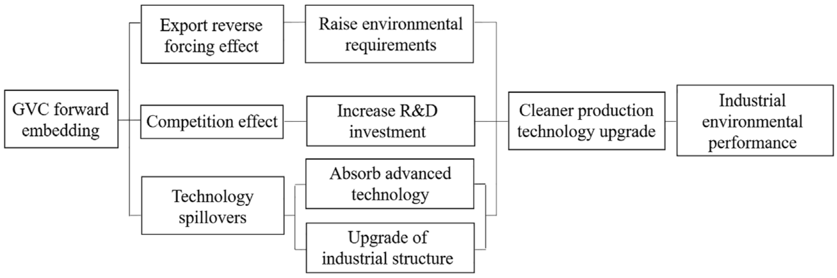


FIGURE 1
Impact mechanism of GVC forward embedding on industrial environmental performance.

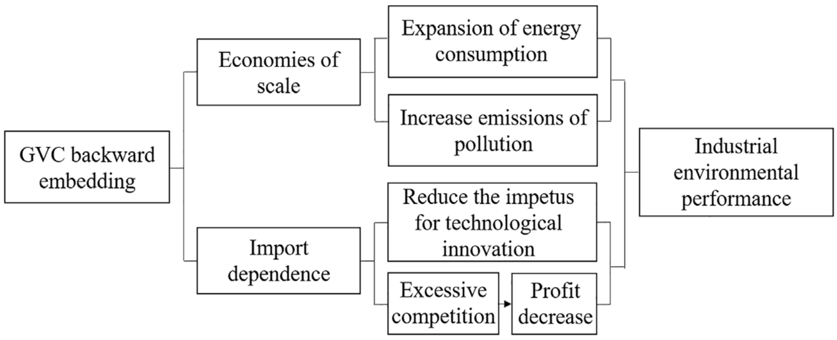


FIGURE 2
Impact mechanism of GVC backward embedding on industrial environmental performance.

Therefore, the industrial environmental performance is further improved. Secondly, the increase of the forward embedding degree of GVC will cause a competitive effect. Facing the competitive pressure from multinational enterprises in developed countries, industrial enterprises in the "Belt and Road" countries need to continuously carry out technological innovation and product upgrading (Bloom et al., 2015). They must increase R&D investment in cleaner production, reduce industrial pollution emissions and increase economic benefits to maintain their competitive advantages, which improves the industrial environmental performance. Finally, the improvement of GVC forward embedding degree leads to the technology spillover effect. When countries along the "Belt and Road" forward embed GVC in the form of export intermediate products, foreign direct investment, and other value output methods, they can establish research and development institutions in developed countries. In this way, they could absorb the talent, technology, and other advantageous resources from developed countries through enterprise mergers and acquisitions (Jiang et al., 2020). In addition, the upgrading of industrial production technology and production equipment is conducive to the transformation and upgrading of industrial structure, which improves the overall economic benefits of the industrial industry and reduces pollution emissions (Du et al., 2021), thus promoting industrial environmental performance. Consequently, Hypothesis 1 of this paper is proposed.

Hypothesis 1. The increase of GVC forward embedding degree will promote the industrial environmental performance of countries along the "Belt and Road".

3.2 Analysis of the inhibitory effect of global value chain backward embedding on environmental performance

The improvement of the backward embedding degree of GVC will restrain the industrial environmental performance of countries along the "Belt and Road", which is realized through the scale economies effect and import dependence effect. Figure 2 is the mechanism diagram of the inhibitory effect of GVC backward embedding on environmental performance.

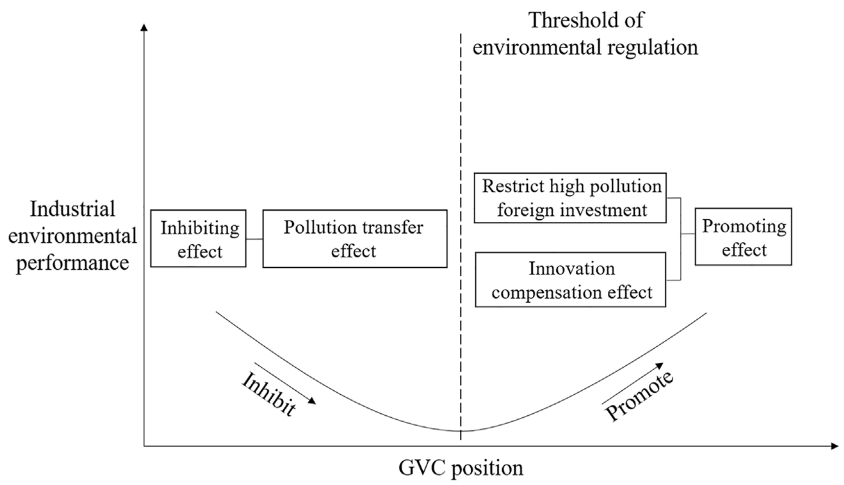


FIGURE 3
Impact mechanism of GVC embedding position on industrial environmental performance.

TABLE 1 ADB_IEA industrial sector matching table.

Industry serial number	IEA database industry name	ADB database industry name
1	Chemicals and petrochemicals	Chemicals and chemical products
2	Non-ferrous metals; iron and steel; non-metallic minerals	Other nonmetallic minerals; basic metals and fabricated metal
4	Transport equipment	Transport equipment
5	Machinery	Machinery, nec
6	Mining and quarrying; food, beverages and tobacco	Mining and quarrying
7	Food, beverages and tobacco	Food, beverages, and tobacco
8	Pulp, paper and print	Pulp, paper, paper products, printing, and publishing
9	Wood and wood products	Wood and products of wood and cork
10	Textiles and leather	Textiles and textile products; leather, leather products, and footwear
11	Construction	Construction
12	Not elsewhere specified	Manufacturing, nec; recycling; coke, refined petroleum, and nuclear fuel; rubber and plastics; electrical and optical equipment

On the one hand, GVC backward embedding will facilitate the “Belt and Road” countries to expand the market scale and further release the production potential, leading to the scale economies effect. The countries along the “Belt and Road” are mainly developing countries, which rely on the advantages of labor and resources to embed the GVC labor division system in the form of raw material processing and processing assembly. These processing and assembly links are high energy-consuming. Therefore, the expansion of the production scale will result in tremendous resource input and energy consumption, which in turn rapidly increases the pollution emissions (Yang et al., 2019). The benefits of economic growth cannot compensate the pollution emissions growth, and the industrial environmental performance is consequently reduced. On the other hand, the backward embedding of GVC will lead to import dependence, which is not conducive to the improvement of industrial environmental performance. When the countries along the “Belt and Road” play the role of “value input” in GVC, the backward embedding degree of GVC increases. The industrial enterprises of developing countries will regard the leading enterprises of developed countries as external learning channels, which weakens

TABLE 2 Descriptive statistics.

Variables	Sample size	Average value	Maximum value	Minimum value	Standard deviation
EP	210	−0.374	0.275	−1.473	0.456
GVCf-pa	210	−1.249	−0.682	−2.323	0.444
GVCb-pa	210	−1.108	−0.480	−2.206	0.415
GVC-po	210	−0.035	0.221	−0.176	0.072
PS	210	24.644	29.382	22.100	1.852
ECS	210	2.705	3.766	1.157	0.625
ED	210	0.002	0.006	−0.005	0.002
R&D	210	−0.018	0.941	−0.963	0.459
GG	210	0.206	0.829	−1.424	0.564
FDI	210	3.786	5.012	−0.084	0.310
TAX	210	3.728	4.269	2.912	0.290

TABLE 3 Variance inflation Factor (VIF).

Variables	(1)		(2)		(3)		(4)	
	VIF	1/VIF	VIF	1/VIF	VIF	1/VIF	VIF	1/VIF
GVCf-pa	4.41	0.22			5.29	0.18		
GVCb-pa			6.78	0.14	8.12	0.12		
GVC-po							3.06	0.32
PS	8.31	0.12	5.42	0.18	8.52	0.11	4.09	0.24
ECS	4.85	0.20	4.20	0.23	5.17	0.19	3.07	0.32
ED	2.64	0.37	2.97	0.33	3.63	0.27	3.76	0.26
R&D	1.55	0.64	1.21	0.82	1.56	0.64	1.45	0.68
GG	4.66	0.21	6.88	0.14	6.88	0.14	4.72	0.21
FDI	1.02	0.98	1.01	0.98	1.02	0.97	1.01	0.98
TAX	1.77	0.56	1.76	0.56	1.90	0.52	1.98	0.50

their motivation to carry out cleaner production technology innovation. At the same time, "value input" activities, such as importing intermediate products, may also cause excessive competition in the domestic industrial market. To maintain market share, domestic industrial enterprises are forced to reduce or even cancel their investment in R&D and innovation of production technology. It increases the difficulty to get rid of its dependence on the existing technologies of developed countries, which is detrimental to the improvement of economic benefits and the reduction of pollution emissions, and plays an inhibitory role on environmental performance (Eichengreen et al., 2007). Accordingly, Hypothesis 2 is proposed.

Hypothesis 2. The increase of GVC backward embedding degree will restrain the industrial environmental performance of countries along the "Belt and Road".

3.3 Analysis of uncertainty relationship between global value chain embedding position and environmental performance

When the environmental regulation level of countries along the "Belt and Road" is low, the improvement of GVC position will aggravate the pollution transfer effect and reduce the industrial environmental performance. The continuous improvement of the environmental regulation level will limit the pollution transfer effect. Beyond a certain "threshold", the improvement of GVC position will promote industrial environmental performance. Therefore, the relationship between the embedding position of GVC and industrial environmental performance is dependent on the changes in the intensity of environmental regulation, which is manifested as a threshold effect. Figure 3 is the mechanism diagram presenting the threshold effect of GVC embedding position on environmental performance.

TABLE 4 Benchmark estimation.

	(1)	(2)	(3)	(4)
GVCf-pa	0.060** (0.025)		0.236*** (0.021)	
GVCb-pa		−0.142*** (0.020)	−0.277*** (0.016)	
GVC-po				0.630*** (0.095)
PS	−0.074*** (0.016)	−0.113*** (0.005)	−0.069*** (0.010)	−0.084*** (0.013)
ECS	−0.041** (0.019)	−0.102*** (0.015)	−0.067*** (0.016)	−0.081*** (0.021)
ED	23.804*** (3.943)	20.568*** (2.969)	34.389*** (2.842)	28.679*** (4.536)
R&D	−0.334*** (0.013)	−0.265*** (0.014)	−0.288*** (0.012)	−0.295*** (0.017)
GG	0.315*** (0.020)	0.388*** (0.016)	0.410*** (0.014)	0.362*** (0.021)
FDI	−0.006 (0.006)	−0.009*** (0.003)	−0.006 (0.006)	−0.006 (0.007)
TAX	0.021 (0.027)	0.024 (0.026)	−0.001 (0.018)	0.011 (0.027)
Constant	1.487*** (0.394)	2.350*** (0.164)	1.370*** (0.257)	1.796*** (0.341)
Wald chi2	2045.36***	4734.29***	2964.30***	1634.34***
Wald test	1570.41***	2206.62***	968.71***	1446.27***
Wooldridge test	32.121***	32.695***	32.340***	32.033***
Pesaran test	1.034	1.566	0.989	0.863

Note: The parentheses are robust standard errors. *, ** and *** indicate significant at the level of 10%, 5%, and 1%.

TABLE 5 Heterogeneity analysis (a).

	(1)	(2)	(3)	(4)
GVCfs-pa	0.054*** (0.018)			
GVCfc-pa		0.053** (0.023)		
GVCbs-pa			−0.091*** (0.024)	
GVCbc-pa				0.009 (0.010)
Control variables	YES	YES	YES	YES
Constant	1.669*** (0.329)	1.478*** (0.412)	1.806*** (0.386)	1.998*** (0.295)
Wald test	1655.94***	1484.91***	1640.24***	1588.25***
Wooldridge test	31.998***	32.734***	34.211***	32.698***
Pesaran test	1.428	1.071	1.596	1.306

Note: The parentheses are robust standard errors. *, ** and *** indicate significant at the level of 10%, 5% and 1%.

TABLE 6 Heterogeneity analysis (b).

	(1)	(2)	(3)	(4)	(5)	(6)
Time span	2007–2014			2015–2020		
GVCf-pa	0.177*** (0.061)			0.255*** (0.078)		
GVCb-pa		−0.149 (0.105)			0.161* (0.090)	
GVC-po			0.997* (0.580)			0.742*** (0.343)
Control variables	YES	YES	YES	YES	YES	YES
Constant	3.719*** (1.085)	5.485*** (0.763)	2.726*** (0.885)	−1.650 (1.188)	1.980 (2.306)	−0.195 (1.373)
Wald test	4028.7***	2153.8***	2223.2***	5239.5***	4373.1***	10420.5***
Wooldridge test	13.582***	10.823***	12.447***	20.059***	21.802***	23.821***
Pesaran test	0.114	−0.209	0.252	2.017**	2.481**	2.385**

Note: The parentheses are robust standard errors. *, ** and *** indicate significant at the level of 10%, 5% and 1%.

TABLE 7 Robustness test.

	(1)	(2)	(3)	(4)	(5)
	Part1		Part2		
GVCf-pa	0.756*** (0.107)		0.575*** (0.017)	0.987*** (0.021)	
GVCb-pa	−1.004*** (0.145)			−0.759*** (0.020)	
GVC-po		3.530*** (0.529)			3.221*** (0.059)
Control variables	YES	YES	YES	YES	YES
Constant	−0.872 (0.909)	0.278 (0.697)	8.446*** (0.327)	7.424*** (0.239)	10.582*** (0.194)
Wu-Hausman	3.719**	6.530**			
Durbin (score) chi2(2)	7.616**	6.648***			
LM statistic	150.859***	156.436***			
F statistic	316.137	754.516			
Wald test			2372.31***	606.37***	984.35***
Wooldridge test			102.375***	88.912***	100.050***
Pesaran test			7.681***	7.475***	7.381***

Note: The parentheses are robust standard errors. *, ** and *** indicate significant at the level of 10%, 5% and 1%.

TABLE 8 Threshold test results.

Explanatory variables	The threshold number	F statistic	1% critical value	5% critical value	10% critical value	The threshold value	95% confidence interval	
ER_{it}	Single threshold	27.19**	31.6461	24.3975	20.3437	−0.4371	−0.4391	−0.4332
	Double threshold	7.63	36.3743	25.8319	22.5422			
	Triple threshold	14.67	64.0711	42.3614	35.3812			

Note: F statistics and critical points were obtained by bootstrap repeated sampling for 300 times. *, ** and *** indicate significant at the level of 10%, 5%, and 1%.

TABLE 9 Threshold model regression results.

	(1)	(2)
Explanatory variables	$ER_{it} \leq \vartheta_1$	$ER_{it} > \vartheta_1$
GVC_po	−2.310*** (0.536)	0.054 (0.430)
PS	0.282*** (0.074)	
ECS	0.250*** (0.084)	
ED	8.202 (22.099)	
R&D	−0.634*** (0.072)	
GG	0.340*** (0.098)	
FDI	−0.007 (0.029)	
TAX	0.140 (0.111)	
Constant	−8.643*** (1.886)	

Note: The parentheses are robust standard errors. *, ** and *** indicate significant at the level of 10%, 5% and 1%.

Specifically, as most of the "Belt and Road" members are developing countries, the intensity of environmental regulation is different from that of developed countries. At the early stage of GVC position promotion, the "Belt and Road" countries are relatively short of capital and technology, and the level of environmental regulation is loose. In order to further promote the GVC position, a large number of industrial capital and advanced production technologies from developed countries will be imported. However, due to the relatively high level of environmental regulation in developed countries, most of the industrial enterprises transferred to the developing countries along the "Belt and Road" are with high energy consumption and high pollution emission, forming a pollution transfer effect and reducing the industrial environmental performance (Li et al., 2021).

It is also shown that, after crossing a certain "threshold" of environmental regulation level, the improvement of GVC embedding position will promote industrial environmental performance. This is because the improvement of environmental regulation level can reduce the pollution transfer effect (Li et al., 2021). With the increasing intensity of environmental regulation in countries along the "Belt and

Road", the entry threshold for foreign capital will be raised. Foreign-funded enterprises with high pollution emissions will be prohibited from entering, and high taxes will be levied on foreign-funded enterprises with high pollution that have entered. In order to meet the higher environmental regulation standards, foreign-funded industrial enterprises will continuously improve the development of cleaner production technology, which indirectly improves the industrial cleaner production level of the "Belt and Road" countries through technology spillovers. In addition, the appropriate improvement of environmental regulation would impose necessary environmental constraints on industrial enterprises and force them to carry out technological innovation (Tang and Li, 2022). The innovation compensation effect brought by environmental regulation can offset the cost of environmental regulation, thus improving the economic efficiency and environmental performance of enterprises. Accordingly, Hypothesis 3 is proposed.

Hypothesis 3. With the continuous improvement of the environmental regulation level of countries along the "Belt and Road", the inhibitory effect of pollution transfer on environmental performance caused by the improvement of GVC position is decreasing. Finally, after the level of environmental regulation crosses a certain "threshold", the improvement of GVC position will promote industrial environmental performance.

4 Model setting, measurement method and data description

4.1 Model setting

In order to verify Hypotheses 1 and Hypotheses 2 proposed in the above theoretical analysis, the benchmark regression model is constructed in this section as follows:

$$EP_{it} = \alpha_0 + \alpha_1 GVCf\_pa_{it} + \alpha_2 GVCb\_pa_{it} + \alpha_3 Z_{it} + \varepsilon_{it} \quad (1)$$

$$EP_{it} = \beta_0 + \beta_1 GVC\_po_{it} + \beta_2 Z_{it} + \varepsilon_{it} \quad (2)$$

In the formulas, EP_{it} is the industrial environmental performance of country i in the year t. $GVCf_{pa_{it}}$ and $GVCb_{pa_{it}}$ is the forward embedding degree and backward embedding degree of GVC. $GVC_{po_{it}}$ is the GVC position, and Z_{it} is the control variable. ϵ_{it} represents the error term. In this paper, some variables are treated with logarithms.

Based on the previous research of other scholars, the control variables in this paper are selected as follows:

(1) Production scale (PS). On the one hand, the expansion of the industrial production scale is conducive to the formation of economies of scale and the industrial cluster effect. Enterprises in the cluster improve the level of cleaner production technology by mutual learning, which has a positive impact on environmental performance. On the other hand, the expansion of the production scale will also cause an increase in energy consumption and emission of pollutants, negatively impacting the environmental performance (Yang et al., 2019). In this paper, industrial added value is used as the characterization of production scale.
(2) Energy consumption structure (ECS). In this paper, the proportion of renewable energy consumption in total energy consumption is used as the characterization of energy consumption structure.
(3) External dependence of energy (ED). Excessive external dependence on energy will reduce the security and stability of the energy supply, and have an impact on the energy demand of industrial enterprises (Yang et al., 2022), which will further affect economic output, pollution emissions, and environmental performance. This paper measures the external dependence of energy from the perspective of net energy import.
(4) Research and development intensity (R&D). The improvement of R&D intensity is conducive to the innovation of cleaner production technology, thereby promoting environmental performance. This paper uses the proportion of R&D investment in GDP to express R&D intensity.
(5) Global governance level (GG). The level of global governance can reflect the effectiveness of government governance. This paper selects the arithmetic mean of the government efficiency index, stability index, regulatory governance index, legal index, corruption regulatory index, and democratic freedom and rights index published by the world bank database as the measurement indicator of the global governance level.
(6) Foreign capital participation (FDI). The inflow of foreign capital in developed countries can produce a technology spillover effect, which is conducive to the improvement of cleaner production technology (Hao et al., 2021). In this paper, the percentage of foreign direct investment inflow in GDP is used as the indicator of foreign capital participation.
(7) Tax level (TAX). Alleviating the host country's tax burden is able to attract the investment of foreign companies, which will have an impact on pollution emissions through technology spillovers. This paper uses the host country's total tax rate as a percentage of business profits to measure the host country's tax burden.

4.2 Core variable measurement and data description

4.2.1 Global value chain embedding degree measurement

Common indicators to measure the degree of GVC embedding include the vertical specialization index and the domestic component in exports, which are from the perspective of trade. Innovatively, Wang et al. (2017a) and Wang et al. (2017b) measured the situation of GVC from the perspective of production. This method overcomes the problem that GVC embeddedness may be overestimated due to low exports calculated from the perspective of trade, thus realizing the scientific quantification of a country's participation in GVC division of labor. Therefore, this study adopts the method from Wang et al. (2017a) and Wang et al. (2017b) to measure the degree of GVC embeddedness. The total production activities of a country are divided into pure domestic production activities, traditional trade production activities, and GVC production activities according to whether the value-added and the use of the value-added flow across borders. Among them, GVC production activities can be divided into simple GVC production activities and complex GVC production activities according to the number of transnational flows of value-added. Specifically, assuming a world economy with G countries and N sectors, A^D is the domestic input coefficient matrix, and A^F is the foreign input coefficient matrix. Y^D is the domestic final product demand matrix. Y^F is the foreign final product demand matrix, and E is the total export matrix. The total output matrix X can be decomposed into:

$$X = AX + Y = A^D X + Y^D + A^F X + Y^F = A^D X + Y^D + E \quad (3)$$

By introducing the Leontief inverse matrix L of domestic production and the Leontief inverse matrix B of world production, and multiplying both sides of the equation by the value-added matrix V, the following formulas can be obtained:

$$X = LY^D + LE = LY^D + LY^F + LA^F X \quad (4)$$

$$\begin{aligned} \hat{V}B\hat{Y} &= \hat{V}L\hat{Y}^D + \hat{V}L\hat{Y}^F + \hat{V}LA^F B\hat{Y} \\ &= \hat{V}L\hat{Y}^D + \hat{V}L\hat{Y}^F + \hat{V}LA^F L\hat{Y}^D + \hat{V}LA^F\left(B\hat{Y} - L\hat{Y}^D\right) \end{aligned} \quad (5)$$

Adding the rows of matrix $\hat{V}B\hat{Y}$ explains how the value-added is used by the department of downstream countries. Therefore, the row summation of the matrix is forward production linkages. Adding the columns of matrix $\hat{V}B\hat{Y}$ explains which upstream countries of value added are used in production. Therefore, the column summation of the matrix is backward production linkages. The row and column summations of the matrix $\hat{V}B\hat{Y}$ can be expressed as:

$$\hat{V}BY = VA' = \hat{V}LY^D + \hat{V}LY^F + \hat{V}LA^F LY^D + \hat{V}LA^F\left(BY - LY^D\right) \quad (6)$$

$$VB\hat{Y} = Y' = VL\hat{Y}^D + VL\hat{Y}^F + VLA^F L\hat{Y}^D + VLA^F\left(B\hat{Y} - L\hat{Y}^D\right) \quad (7)$$

The above formulas divide a country's production activities into four parts according to the source, destination and cross-border times of value-added: 1) $\hat{V}L\hat{Y}^D$ represents purely domestic production activities (D), which only meets the domestic demand of production and consumption and does not involving any international trade and multinational flow. 2) $\hat{V}L\hat{Y}^F$ represents traditional trade production activities (RT). The value added is not involved in the production roundabout process abroad, and it is circulated across the border for consumption. 3) $\hat{V}LA^F L\hat{Y}^D$ represents simple GVC production activities (GVC_S). In this case, the value added is circulated across the border for production. 4) $\hat{V}LA^F(B\hat{Y} - L\hat{Y}^D)$ represents complex GVC production activities (GVC_C). According to the destination of the export product, it can be divided into the part that is returned to and absorbed by the exporting country and the part that is re-exported to the third country and absorbed by other countries. In the complex GVC production activity, the added value flows across the country at least twice.

On this basis, the GVC forward embedding degree index and GVC backward embedding degree index can be constructed by distinguishing forward production linkages and backward production linkages as follows:

$$\begin{aligned} GVCf\_pa &= \frac{\text{V\_GVC}}{VA'} = \frac{\text{V\_GVC\_S} + \text{V\_GVC\_C}}{VA'} \\ &= \frac{\hat{V}LA^F LY^D + \hat{V}LA^F\left(BY - LY^D\right)}{VA'} \end{aligned} \quad (8)$$

$$\begin{aligned} GVCb\_pa &= \frac{\text{Y\_GVC}}{Y'} = \frac{\text{Y\_GVC\_S} + \text{Y\_GVC\_C}}{Y'} \\ &= \frac{VLA^F L\hat{Y}^D + VLA^F\left(B\hat{Y} - L\hat{Y}^D\right)}{Y'} \end{aligned} \quad (9)$$

$GVCf\_pa$ is the GVC forward embedding degree index. The higher the degree of forward embedding, the more "value output" activities with high added value such as raw material supply, R&D design, and core parts production and supply, are undertaken by the department in the production link. $GVCb\_pa$ is GVC backward embedding degree index. The higher the degree of backward embedding, the more the department undertakes "value input" activities with low added value, such as processing and assembly in the production link. Since GVC activities can be divided into simple cross-border production activities and complex cross-border production activities according to the cross-border times of value-added, the degree of GVC forward embedding can be further decomposed into GVC forward simple embedding degree ($GVCfs\_pa$) and GVC forward complex embedding degree ($GVCfc\_pa$). The degree of GVC backward embedding can be further decomposed into the degree of GVC backward simple embedding ($GVCbs\_pa$) and the degree of GVC backward complex embedding ($GVCbc\_pa$) as follows:

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$$GVCfs\_pa = \frac{V\_GVC\_S}{VA'} = \frac{\hat{V}LA^F LY^D}{VA'} \quad (10)$$

$$GVCfc\_pa = \frac{V\_GVC\_C}{VA'} = \frac{\hat{V}LA^F (BY - LY^D)}{VA'} \quad (11)$$

$$GVCbs\_pa = \frac{Y\_GVC\_S}{Y'} = \frac{VLA^F L\hat{Y}^D}{Y'} \quad (12)$$

$$GVCbc\_pa = \frac{Y\_GVC\_C}{Y'} = \frac{VLA^F\left(B\hat{Y} - L\hat{Y}^D\right)}{Y'} \quad (13)$$

4.2.2 Global value chain embedding position measurement

This paper draws on the measurement method of Koopman et al. (2010), and calculates a country's GVC embedded position according to the following expression.

$$GVC\_po_{it} = \ln\left(1 + \frac{IV_{it}}{E_{it}}\right) - \ln\left(1 + \frac{FV_{it}}{E_{it}}\right) \quad (14)$$

In the above formula, IV_{it} is the indirect domestic added value in a country's exports. FV_{it} is the foreign added value in exports, and E_{it} is the total export. $\frac{IV_{it}}{E_{it}}$ is GVC forward participation, while $\frac{FV_{it}}{E_{it}}$ is GVC backward participation. GVC_po_{it} is GVC position. The higher the value of GVC_po_{it}, the higher its position in GVC division of labor, and the closer it is to the upstream link of GVC.

4.2.3 Measurement of industrial environmental performance

The super-efficiency SBM-DEA model not only considers the expansion of desired output (such as added value) and the reduction of undesired output (such as carbon dioxide), but also accurately calculates the decision-making units (DMUs) whose efficiency value exceeds 1. It is more in line with the production needs of decision makers and has been widely used in the measurement of environmental performance. Therefore, this method is utilized in this study to measure the environmental performance of China's manufacturing industry, and the model is constructd as follows:

$$min\,\rho = \frac{1 + \frac{1}{m}\sum_{i=1}^{m} s_i^- \Big/ x_{ik}}{1 - \frac{1}{q_1+q_2}\left(\sum_{r=1}^{q_1} s_r^+ \Big/ y_{rk} + \sum_{i=1}^{q_2} s_t^{b-} \Big/ b_{rk}\right)} \quad (15)$$

s.t. $\sum_{j=1, j\neq k}^{n} x_{ij}\lambda_j - s_i^- \leqslant x_{ik}$

$$\sum_{j=1, j\neq k}^{n} y_{rj}\lambda_j + s_r^+ \geqslant y_{rk}$$

$$\sum_{j=1, j\neq k}^{n} b_{ij}\lambda_j - s_t^{b-} \leqslant b_{tk}$$

$$1 - \frac{1}{q_1+q_2}\left(\sum_{r=1}^{q_1} s_r^+/y_{rk} + \sum_{i=1}^{q_2} s_t^{b-}/b_{rk}\right) > 0$$

In the above equation, λ, s^+, $s^- \geq 0$; i = 1, 2, . . ., m; r = 1, 2, . . ., q; j = 1, 2, . . ., n (j≠k). m is the number of inputs. q is the number of outputs, and ρ is the environmental performance. When ρ approaches 0, it indicates that the environmental performance of the evaluated DMU is low, and when ρ approaches or even exceeds 1, it indicates that the environmental performance of the evaluated DMU is high. s_i^-, s_r^+ and s_t^{b-} are the slack variables of input, desired output, and undesired output, respectively. Total industrial energy final consumption (TFC), number of industrial workers, and industrial R&D investment capital are selected as input indicators. Industrial added value is adopted as the desired output indicator, and industrial carbon dioxide emission is the undesired output indicator.

4.2.4 Measurement of the environmental regulation intensity

In this paper, the entropy method is selected to measure the environmental regulation intensity. It is an objective weighting method, which can determine the weight of the index according to the impact of the relative change degree of the index on the whole system. The index with a greater relative change degree has a greater weight. The initial data matrix composed of N indicators in the evaluation index system is as follows:

$$X = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix} \quad (16)$$

In order to eliminate the impact caused by different dimensions of indicators on the results, data should be standardized. The positive index is $X'_{ij} = \frac{X_{ij} - min\{X_{ij}\}}{max\{X_{ij}\} - min\{X_{ij}\}}$, and the negative index is $X'_{ij} = \frac{max\{X_{ij}\} - X_{ij}}{max\{X_{ij}\} - min\{X_{ij}\}}$. The ratio of the item j index value in the year i is $Y_{ij} = X'_{ij}/\sum_{i=1}^{m} X'_{ij}$ .In this case, the information entropy and information redundancy are calculated as follows:

$$e_j = -\sum_{i=1}^{m}\left(Y_{ij} \times \ln Y_{ij}\right)\Big/ \ln m \;\; e_j > 0 \quad (17)$$

$$d_j = 1 - e_j \quad (18)$$

The index weight and evaluation score of the single index are calculated as:

$$W_i = d_j\Big/\sum_{j=1}^{m} d_j \quad j = 1, 2 \ldots m \quad (19)$$

$$S_{ij} = W_i \times X'_{ij} \quad (20)$$

where X_{ij} is the value of the item j evaluation index in the year i. $max\{X_i\}$ and $min\{X_j\}$ are the maximum and minimum values of the evaluation index in all years. m is the number of evaluation years, and n is the number of indicators. The carbon dioxide emission per unit GDP, the percentage of wastewater undergoing primary treatment, and the proportion of solid waste treatment are selected as the evaluation indexes of environmental regulation from the perspective of industrial waste gas, waste water, and solid waste treatment. The carbon dioxide emission per unit GDP is a negative evaluation index. The percentage of wastewater undergoing primary treatment and the proportion of solid waste treatment are positive evaluation indexes.

4.2.5 Data description

The industrial sectors of the countries along the "Belt and Road" from 2007 to 2020 are taken as the research object in this study. To ensure the statistical caliber consistency, this paper matches and combines the Asian Development Bank (ADB) Regional Input-Output Tables with the International Energy Agency (IEA) classification standards for the industrial sector. The scope of the industrial sector studied in this paper is then determined as shown in Table 1. Meanwhile, in view of the data availability, this paper mainly studies the industrial sectors of 15 countries[1] contained in the Asian Development Bank Regional Input-Output Tables with a sample size of 210. The descriptive statistics of the variables are shown in Table 2. There is no outlier found in the statistical results, indicating the good statistical quality of the data. The data are all from the Asian Development Bank database, IEA database, World Bank database, and Yale University Environmental Performance Evaluation Index Database.

5 Analysis and test of empirical results

5.1 Multicollinearity test

The multiple collinearity test is conducted using the variance inflation factor, and the test results are shown in Table 3. It can be seen that the maximum value of the variance inflation factor is 8.52, which is lower than the empirical value of 10, manifesting the absence of the problem with multicollinearity.

5.2 Analysis of benchmark regression results

Before the benchmark regression, Wald test, Wooldridge test, and Pesaran test are conducted. The test results are shown in the last three rows of Table 4. It can be seen that the results of Wald test and Wooldridge test are significant, which proves that the regression model has the problems of heteroscedasticity and autocorrelation, which may lead to the failure of ordinary OLS estimation. In order to solve the problems, following the method of Jiang and Li (2021), the comprehensive feasible generalized least squares (FGLS) method is used to perform the regression of the benchmark model. Table 4 shows the regression results.

Columns 1–3 of Table 4 show the regression results of GVC forward embedding degree and GVC backward embedding degree on the industrial environmental performance of countries along the "Belt and Road". It can be seen that the regression result of the forward embedding degree of GVC is significantly positive, indicating that the increase of the GVC forward embedding degree promotes the industrial environmental performance, which proves Hypothesis 1. The regression result of the backward embedding degree of GVC is significantly negative, indicating that the increase of the backward embedding degree of GVC has an inhibitory effect on the industrial environmental performance of countries along the "Belt and Road", and Hypothesis 2 is proved. The reason is that, on the one hand, with the improvement of GVC forward embedding degree, when industrial enterprises in the "Belt and Road" countries participate in GVC in the form of "value output" such as export of intermediate products, the strict environmental regulation standards of importing countries will urge the enterprises of exporting countries to carry out cleaner production technology innovation and reduce pollution emissions. The innovation of cleaner production technology is also conducive to upgrading the structure of domestic export industries, promoting the transfer of industrial production factors to high-tech and high-productivity enterprises, and improving the economic efficiency and environmental performance of the whole industry. On the other hand, the improvement of the backward embedding degree of GVC will rapidly expand the industrial production scale. Since most of the "Belt and Road" members are developing countries, they are embedded in GVC mainly through processing and assembly with low added value and high pollution emissions. The expansion of the production scale will lead to an increase in energy consumption and the expansion of pollution emissions, which will inhibit the industrial environmental performance. At the same time, the increase in the backward embedding degree of GVC may also make industrial enterprises in developing countries along the "Belt and Road" rely on imported industrial intermediate products from developed countries. This overdependence reduces the capacity of independent R&D, and is detrimental to the innovation of cleaner production technology and the improvement of environmental performance.

The fourth column of Table 4 shows the regression results of GVC embedding position on the industrial environmental performance. It can be seen that the regression result of GVC embedding position without considering the impact of uncertainty is significantly positive, which indicates that the improvement of GVC embedding position has a promoting effect on industrial environmental performance. The reason is that, first of all, the improvement of GVC position can help enterprises to achieve a production model with high added value and low pollution emissions through technical effects.

1 15 countries along the "Belt and Road" include Czech Republic, Estonia, Croatia, Hungary, Lithuania, Latvia, Poland, Slovakia, Slovenia, Bulgaria, China, India, Romania, Russia, Turkey

Secondly, in the process of rising GVC embedded position, low-energy-efficiency enterprises with high pollution will be gradually eliminated, and the energy efficiency of the industry will be improved. Finally, the process of rising GVC position is accompanied by industrial upgrading. Production factors are gradually transferred from low value-added links to high value-added links, improving the economic benefits and environmental performance of the industry.

From the perspective of control variables, the regression coefficient of production scale (PS) is significantly negative, which may be because the expansion of production scale will increase energy consumption and inhibit industrial environmental performance. The regression result of energy consumption structure (ECS) is significantly negative. That may be because the replacement of traditional energy by clean energy is accompanied by the renewal of production equipment, which will increase production costs and reduce environmental performance in the short term. The regression coefficient of external dependence of energy (ED) is positive, indicating that the dependence of industrial enterprises in countries along the “Belt and Road” on imported energy is conducive to the improvement of industrial environmental performance. The regression coefficient of research and development intensity (R&D) is significantly negative. This may be because the R&D Investment occupies the share for marketing and other activities to a certain extent, resulting in the phenomenon of resource misallocation, which is not conducive to the improvement of environmental performance. The regression coefficient of the global governance level (GG) is significantly positive, indicating that improving the effectiveness of government governance of countries along the “Belt and Road” is conducive to the increase of industrial environmental performance. The regression coefficient of foreign capital participation (FDI) is negative, which may be because most of the foreign direct investment from developed countries is concentrated in high pollution emission industries, increasing energy demand and pollution emissions, and inhibiting environmental performance. The coefficient of TAX level (TAX) changes with different embedding directions of GVC. When a country embeds GVCs in the forward and backward directions at the same time, the excessively high level of tax burden will reduce industrial profits, which is not conducive to the improvement of environmental performance.

5.3 Heterogeneity analysis

5.3.1 Heterogeneity analysis of global value chain embedding degree based on cross-border times of the added value

In the benchmark regression analysis, the impacts of GVC forward embedding degree and GVC backward embedding degree on the industrial environmental performance are empirically tested. In the heterogeneity analysis in this section, the GVC forward embedding degree is further divided into GVC forward simple embedding degree and GVC forward complex embedding degree, according to the cross-border times of added value. In the same way, the GVC backward embedding degree is divided into GVC backward simple embedding degree and GVC backward complex embedding degree. The regression results are shown in Table 5.

It can be seen from the heterogeneity test results in Table 5 that, the regression results of GVC forward simple embedding degree and GVC forward complex embedding degree are significantly positive, which is consistent with the regression results of GVC forward embedding degree in the benchmark regression. However, the regression result of backward simple embedding of GVC is significantly negative, and the regression result of backward complex embedding of GVC is promotive, which indicates that the impact of backward embedding of GVC is complex. The inhibitory effect of backward embedding of GVC on the industrial environmental performance of countries along the “Belt and Road” is mainly brought by backward simple embedding of GVC. The reason is that the backward simple embedding involves only one cross-border production. There are a few countries and sectors involved in the production chain, and the production is often dominated by low value-added and high energy consumption links, such as processing and assembly. The requirements for the technical content and product quality of production are low, and the generated pollution emissions are high, thus causing a significant inhibition effect on environmental performance. However, in the backward complex embedding of GVC, the frequency of cross-border production increases. The production chain is longer, and the technical complexity and environmental protection standards are improved. The inhibitory effect of backward complex embedding on environmental performance is weakened. Therefore, the inhibitory effect of backward embedding of GVC on environmental performance is mainly brought by backward simple embedding.

5.3.2 Temporal heterogeneity before and after the implementation of the “Belt and Road” initiative

In order to consider the impact of the implementation of the “Belt and Road” initiative, two time periods, namely 2007–2014 and 2015–2020, are selected to compare and test the impact of GVC embedding on industrial environmental performance. The test results are shown in Table 6. It can be seen that before and after the implementation of the “Belt and Road” initiative, the impact of GVC forward embedding and GVC position on environmental performance remains consistent. However, the impact of GVC backward embedding on environmental performance has changed from inhibition to promotion, indicating that the implementation of the “Belt and

Road" initiative promotes the industries to improve environmental performance through GVC backward embedding. The reason is that the "Belt and Road" initiative is conducive to the complementary advantages of countries, which improves the level of production technology. For example, during the cooperation in the field of mineral resources under the "Belt and Road" initiative, Central Asian countries are rich in oil and gas resources, but their exploration and development capabilities are relatively weak. Southeast Asia is rich in mineral resources, but the infrastructure construction is relatively weak. However, China is superior in mineral development equipment and technology, and has strong industrial complementarity with Central and Southeast Asian countries. Central and Southeast Asian countries can cooperate with China through the "Belt and Road" initiative to improve the technical level of the mining industry and increase the economic benefits of GVC backward embedding, which promotes environmental performance.

5.4 Robustness test

5.4.1 Endogeneity test

The impact analysis of GVC embedding on the industrial environmental performance may encounter the problems such as reverse causality or missing variables, which causes endogeneity, and then affects the regression results. Therefore, the lag one phase of GVC forward embedding degree, GVC backward embedding degree, and GVC embedding position is used as instrumental variables, and the two-stage least square method (2SLS) is adopted to examine whether the benchmark regression model is endogenous. The test results are shown in columns (1) and (2) of Table 7. It can be seen that, first of all, the Wu-Hausman results are significant, which means that the benchmark regression models all have significant endogeneity problems. Secondly, the selection of instrumental variables in this study is reasonable. The *p* values of LM statistics are all less than 0.01, which indicates that there is no such issue of insufficient identification of instrumental variables. The results of weak instrumental variables show that the value of F statistics is much greater than the empirical value of 10, which rejects the hypothesis of weak instrumental variables. Since the regression model is exactly identified, there is no need to perform over-identification test. Finally, the endogeneity test results are consistent with the benchmark regression results, that is, GVC forward embedding and the improvement of GVC position significantly promote environmental performance, while GVC backward embedding significantly inhibits environmental performance.

It should also be noted that when the lag one phase of the GVC embedding is adopted as the instrumental variables for regression, the absolute values of the regression results of GVC forward embedding degree, backward embedding degree and position are 0.756, 1.004, and 3.530, respectively, which are significantly larger than the absolute values of the benchmark regression results of 0.236, 0.277 and 0.630. It presents the potential endogenous problems may underestimate the impact of GVC embeddedness on industrial environmental performance [2].

5.4.2 Replacing the explained variable

In order to further test the robustness of the results, the method of replacing the explained variables is employed, and the single factor carbon productivity is used as the representation of environmental performance. The single factor of carbon productivity is the ratio of a single economic index to carbon emissions, which reflects the low-carbon production capacity of the industry (Zhang et al., 2018). The ratio of industrial added value to industrial carbon emissions is used in this study to measure the single factor carbon productivity. The test results are shown in columns (3)–(5) of Table 7. It can be seen that although the explained variables are replaced, the results of the core explanatory variables are still significant and the coefficient sign remains unchanged, which proves that the models and conclusions constructed in this paper are robust.

6 Further research

According to the above theoretical analysis, it is speculated that the relationship between the embedding position of GVC and the industrial environmental performance of the "Belt and Road" countries is dependent on the intensity of environmental regulation, showing a threshold effect. Therefore, the threshold model is adopted in this section to investigate the different effects of the GVC embedding position rising on industrial environmental performance with the change of environmental regulation intensity. Referring to the panel threshold model proposed by Hansen (1999), the threshold model is constructed as follows:

$$\mathrm{EP}_{\mathrm{it}} = \gamma_0 + \gamma_1 GVC\_po_{it} \cdot I(ER_{it} \le \vartheta) + \gamma_2 GVC\_po_{it} \cdot I(ER_{it} > \vartheta) + \gamma_3 Z_{it} + \varepsilon_{it} \tag{21}$$

$$I(ER_{it} \le \vartheta) = \begin{cases} 1 \; if \; ER_{it} \le \vartheta \\ 0 \; if \; ER_{it} > \vartheta \end{cases} \tag{22}$$

2 The change of the coefficient means that, in the benchmark regression results, each increase in the GVC forward embedding degree, backward embedding degree, and embedding position by one unit will cause changes in environmentalperformance by 0.236, 0277, and 0.630 units, respectively. After considering endogeneity, the impact of GVC embedding on environmental performance increased to 0.756, 1.004, and 3.530. It shows that the impact of GVC embeddings onenvironmental performance is underestimated in benchmark regressions.

$$I(ER_{it} > \vartheta) = \begin{cases} 1\ if\ ER_{it} > \vartheta \\ 0\ if\ ER_{it} \le \vartheta \end{cases} \quad (23)$$

where EP_{it} is the environmental performance, and GVC_po_{it} is the GVC position index. ER_{it} is the intensity of environmental regulation. ϑ is the threshold value, and Z_{it} is the control variable. ε_{it} is the error term, and I(·) is the indicative function. Referring to the method of Hansen (1999), three threshold values are set in this study, and the environmental regulation intensity ER_{it} is used as the threshold variable. The threshold test results are shown in Table 8. A significant single threshold effect is observed, while the double threshold and the triple threshold are not significant. The threshold value of the environmental regulation intensity is -0.4371.

Regression estimation is performed on Eq. 21 based on the obtained threshold value, and the results are shown in Table 9. It can be seen that when the countries along the "Belt and Road" are in low intensity level of environmental regulation, the rise of GVC position will inhibit industrial environmental performance. Only when the intensity of environmental regulation is high, will the rise of GVC position promote industrial environmental performance. Hypothesis 3 is thus proved. This is because, on the one hand, the enhancement of the intensity of environmental regulation can restrict the entry of foreign enterprises with high energy consumption and high pollution emissions, and the pollution transfer effect caused by the improvement of GVC position is limited. On the other hand, the improvement of environmental regulation can promote domestic industrial enterprises to carry out production technology innovation, which encourage the countries along the "Belt and Road" to break through the technological blockade in the process of GVC's rising position. The consequences are the improvement of the enterprise profits and the promotion of the industrial environmental performance.

7 Conclusion and policy implications

Based on the industrial sector data of 15 countries along the "Belt and Road" from 2007 to 2020, the impacts of GVC embedding degree and embedding position on industrial environmental performance are systematically examined in this study. It is found that the increase of GVC forward embedding degree promotes industrial environmental performance, and the increase of GVC backward embedding degree is inhibitive. The impact of GVC embedding position on industrial environmental performance shows a significant threshold effect subject to the environmental regulation intensity. Only when the level of environmental regulation continues to rise and crosses the threshold, can the rise of GVC position promote industrial environmental performance. The results of heterogeneity analysis show that backward simple embedding of GVC has a significant inhibitory effect on industrial environmental performance, while the effect of backward complex embedding of GVC is contrary. On the other hand, after the implementation of the "Belt and Road" Initiative, the impact of GVC backward embedding on environmental performance will change from inhibitory to promotive.

According to the conclusions of this study, the policy implications are given as follows:

(1) Most of the "Belt and Road" countries are in the middle and low end of GVC. They should not only actively integrate into the GVC production division, but also guard against the pollution transfer from developed countries, so as to avoid becoming the "Pollution Refuge" for developed countries. Specifically, on the one hand, countries along the "Belt and Road" need to increase their investment in industrial R&D and improve their cleaner production R&D capabilities, in order to form comparative advantages in the process of GVC forward embedding. On the other hand, the "Belt and Road" countries need to balance the relationship between the expansion of production scale caused by backward embedding of GVC and pollution control. In particular, the inhibitory effect of simple backward participation of GVC on environmental performance should be reduced through multi-country cross-border cooperation within the region.

(2) Countries along the Belt and Road should increase the intensity of environmental regulation to reduce the pollution transfer effect caused by GVC embedding. Firstly, the "Belt and Road" countries should improve domestic environmental legislation and strengthen environmental law enforcement to narrow the gap with developed countries in environmental regulation intensity and reduce the risk of pollution transfer in the process of GVC embedding. Secondly, the government should increase subsidies for the development and utilization of industrial clean energy and provide financial support for enterprises' clean production. Finally, the government needs to optimize the implementation form of environmental regulation. The environmental regulation can be implemented in multiple forms, such as emission right trading, environmental tax and emission fee, to develop an effective mechanism for environmental regulation to promote cleaner production technology innovation of enterprises.

(3) The "Belt and Road" members should formulate differentiated embedded GVC policies according to their own development level. For countries with high level of production technology, industrial cooperation and technology sharing should be strengthened, and high-level industrial parks should be built to attract investment from high-tech foreign-invested enterprises. Moreover, they should rely on their advantages in R&D and design, industrial brand building, and other aspects to embed GVC's high-end links. The countries with relatively weak production technology should eliminate the local protectionism and overcome the barriers to the flow of industrial production factors and reduce the backward simple embedding degree of GVC.

This paper presents a new way to realize industrial cleaner production from the perspective of GVC embedding, which provides a theoretical basis and policy support for countries along the "Belt and Road" to weigh and coordinate the economic benefits and environmental costs of participating in GVC. It is also an important expansion and supplement to the relationship between trade and environment. However, there are still some limitations in this study. On the one hand, only the manufacturing industry level is analyzed, lacking the micro-level analysis of the enterprise. On the other hand, in the theoretical analysis part, this paper mainly puts forward theoretical hypotheses on the basis of combing the existing literature and theories. However, how to model the impact mechanism of GVC embedment on environmental performance needs to be considered. Therefore, the evolution characteristics of GVC may be integrated in further research to explore the impact mechanism of GVC embedding on environmental performance from the micro perspective of enterprises.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

YL: conceptualization, methodology, and writing (original draft); YW: formal analysis, data processing and writing (review and editing); XZ: data collection, validation and writing (review and editing); QH: validation, supervision and writing (review and editing).

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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