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RESEARCH ARTICLE

Why is pollution embodied in Guangdong exports declining? The roles of trading scale, technology and structural changes

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Abstract: From 2007 to 2017, Guangdong exports grew at an average rate of 9.6%, while the energy consumption and carbon emission embodied in these trades demonstrated a declining trend. Is total real pollution embodied in exports showing the same trend? If so, what accounts for these changes? Prior studies have provided three explanations, producing greater amount of goods ("the scale effect"), adopting cleaner technologies in production processes ("the technology effect"), and producing proportionally more goods that are environmental-friendly ("the structural effect"). Question then arises as which factor is the driving force of such cleanup in the export business? To answer these questions, an EIO-LMDI (Environmental Input-Output and Logarithmic Mean Divisia Index) model is built to conduct a structural decomposition analysis of pollution embodied in Guangdong exports. We calculate that the pollution embodied in Guangdong export fell by 63 to 85 percent, depending on the pollutants. We further conclude that these pollution reductions are primarily driven by the technology advancement, with some industries, including the clothing industry, communications, computers and other electronic equipment, being more sensitive to the changes in technologies than others. The structural effect is more ambiguous. It only contributes to pollution reduction when the industry itself is pollution intensive.

Keywords: exports, embodied pollution, technology effect, IO-LMDI

1 Introduction

Guangdong, the biggest exporting area in China, accounts for on average 28% of the overall exports in China in the last decade, with a steady growing rate at 9.6% during the same period [1] . Whereas the energy consumptions and carbon emissions embodied in the exports are reported to be decreasing at a startling pace [2–4]. Once the most polluted area in the country, Guangdong has hard-fought its way to be among the cleanest cities in the nation over the years, by implementing numerous sets of policies to alleviate the environmental problem induced by industrial development [2] . In recent decade, most of these attentions are placed on structural upgrading and technology clean-up [5] . Guangdong has been pushing to upgrade its export structure, by limiting the of pollution-intensive products. Would these policies relate to the changes of the embodied pollution in trade?

Previous research suggests three possible explanations for changes in the environmental impacts from trades [6–8]. First, the scale effect: if the overall size of the trade is increasing, with all other influences remain constant, the emissions would increase. Second, the technology effect, suggesting that with cleaner or more effective production technologies, or in other words, with a lower pollution intensity, the same products could be manufactured with less pollution. Third, the structural effect, if the overall structure of the industry consists more products whose production processes involve less pollution, the pollution embodied in the whole industry is less.

The goal of this paper is to first calculate the total actual pollution embodied in Guangdong export and how it changed from 2007 to 2017, and secondly, to understand the underlying forces that have caused such changes. We do this in two complementary steps. We begin by calculating the total pollution emissions from exports over the period from 2007 to 2017, as well as the changes over the selected period, using an EIO model combing data from 23 industry sectors and relating pollution statistics. Then by decomposing the changes in pollution emissions into changes due to the scale of exports, the pollution intensity of a given industry sector, and the composition of the export industry, with LMDI method, we allocate credits for each of the influencing factor.

Figuring out the actual pollution change embodied in export and further allocating credit for the cleanup of export is important not only to Guangdong, and to other export-dominated regions. It provides clear evidence on understanding how policies on structural changes and technology regulation affect the actual pollution. Over the years, the exporting goods of Guangdong were mainly manufactured products that were at the bottom of the so-called "smile curve", keeping the export in the least profitable but most resource intensive segment of the supply chain [9] . The Guangdong government has noticed this low-end lock-in dilemma, and has been pushing to upgrade its export structure and to encourage technology advancement. These efforts seem to pay off as the embodied energy consumptions and carbon emissions in export trades are reported to be declining. This paper helps to further quantify the contributions of structural changes and technology advancement.

This paper differs itself from existed research in two ways. First, it provides new evidence suggesting that the actual pollution embodied in trade declined sharply in recent decade in Guangdong. A second contribution of this study is to quantify these changes and further explaining the reasons for such clean-up.

We present empirical evidence to assess the relative magnitudes of these three effects as they apply to trade in Guangdong.

The following sections are organized as follows. Section 2 presents the method and data used to calculate the provincial embodied pollution of Guangdong export. Detailed description is also provided on the decomposition approach, which combines the input-output method with LMDI to analyze the drivers of the clean-up. Section 3 presents the results and further explores the effects of each factor on the changes in the selected pollutants. Finally, section 4 presents the conclusion and policy implications.

2 Method and data

2.1 Embodied pollution accounting method

To estimate the total embodied pollution, not only the direct pollution embodied in the exports, but also the one generated by intermediate inputs to exports, we develop Equation (1) based on the Leontief input-output framework.

P represents the total embodied pollution, $(I$ - $A)^{-1}$ is the Leontief total requirements matrix, where I is the identity matrix, and A, the 23 $\times$ 23 matrix of direct requirements coefficients with elements A_{ij} representing the RMB value of input industry i needed to produce one RMB's worth of output industry j. By multiplying the Leontief total requirements matrix by the direct pollution coefficients E which reflects the amount of direct pollution per unit output in industry, we can get the matrix of total pollution coefficients: $E(I$ - $A)^{-1}$.

To generate the total pollution embodied in exports, the 23 $\times$ 23 matrix of total export demand Y is introduced in the equation. Hence, the total embodied pollution from exports is calculated as follows:

$$P = E(I - A)^{-1}Y \tag{1}$$

2.2 Decomposition method

Input–output analysis has been often applied to estimating embodied energy, CO_2 emissions, pollutants and land appropriation from international trade activities [5]. And the LMDI approach has its advantages over other composition methods in decomposing [10, 11]. Even though this type of decomposition has been studied and explored by many other scholars, going back at least to Wassily Leontief [12] , it has seldom been applied to calculate the total pollution.

To decompose the changes in embodied pollution from all 23 exporting sectors of Guangdong, and to further conduct a decomposition analysis of the factors causing such changes, we combined the provincial input-output model and the LMDI approach.

Based on Equation (1), the change in P between year t1 to t2 can be decomposed as:

$$\Delta \mathrm{P} = \sum_{i=1}^{n} P_i^{\mathrm{t2}} - \sum_{i=1}^{n} P_i^{\mathrm{t1}} = \mathrm{tec}_{\mathrm{eff}} + \mathrm{str}_{\mathrm{eff}} + sc_{\mathrm{eff}} \tag{2}$$

$$tec_{\mathrm{eff}} = \sum_{i=1}^{n} L\left(P_i^{\mathrm{t2}}, \mathrm{P}_i^{\mathrm{t1}}\right) \ln\left(g_i^{\mathrm{t2}} / \mathrm{g}_i^{\mathrm{t1}}\right) \tag{3}$$

$$str_{\mathrm{eff}} = \sum_{i=1}^{n} L\left(P_i^{\mathrm{t2}}, \mathrm{P}_i^{\mathrm{t1}}\right) \ln\left(y_i^{\mathrm{t2}} / \mathrm{y}_i^{\mathrm{t1}}\right) \tag{4}$$

$$sc_{\text{eff}} = \sum_{i=1}^{n} L\left(P_i^{t2}, \mathrm{P}_i^{t1}\right) \ln\left(y^{t2}/\mathrm{y}^{t1}\right) \tag{5}$$

$$\text{where} \qquad L\left(P_i^{t1}, P_i^{t2}\right) = \left(P_i^{t1} - P_i^{t2}\right) / \ln\left(\frac{P_i^{t2}}{p_i^{t1}}\right) \tag{6}$$

where ΔP represents the embodied pollution change, tec$_{eff}$, str$_{eff}$ and sc$_{eff}$ represent the variation in technical, structural and scale effects in the embodied pollution of Guangdong export from t1 to t2. G$_i$ represents the total pollution coefficient of sector i. The objective was to disentangle the impacts of technological advancement, structural upgrading and scale expansion on pollution changes in international trade. Equation (3) of technical effect explains what happens to total embodied pollution if the pollution coefficient changes, holding the other two factors unchanged. Equation (4) explains the changes of embodied pollution caused by the changes of the proportion of a given sector i in the total export, holding technical and scale effect fixed. And finally, Equation (5) explains how the total embodied pollution change as the scale changes, with the other factors remain unchanged.

2.3 Data source and preparation

This study uses the industrial input-output tables of Guangdong Province between 2007 and 2017 [13] , and we re-organized the original 42 sectors into 23 sectors by categories (see Table 1). It also includes the emissions data for four common pollutants including COD, ammonia nitrogen (AN), NO_x and SO_2 from the Guangdong Environmental Statistical Yearbook for 2007 and 2017 [14, 15]. To eliminate the price influences, we adjusted the 2017 price to be comparable to that in 2007.

Table 1 Industrial sectors categories in this study with the original sector code

Sector code	Industry Sector
S1	coal mining
S2	oil and gas mining
S3	metal mining and processing
S4	nonmetal mining and processing
S5	food and tobacco
S6	textile
S7	clothing
S8	timber and furniture
S9	paper and paper products for cultural, educational and sports
S10	petroleum, coking, nuclear fuel products
S11	chemicals and chemical products
S12	nonmetal mineral products
S13	metals smelting and pressing
S14	metal products
S15	general and special machinery
S16	transport equipment
S17	electrical machinery and equipment
S18	communications, computers and other electronic equipment
S19	measuring instruments and machinery
S20	other industrial activities
S21	production and distribution of electricity and heat
S22	gas supply
S23	water supply

3 Pollution embodied in Guangdong exports

3.1 Embodied emissions change by pollutant

As shown in Table 2, the embodied emissions in Guangdong exports of all four key pollutants in 2017 dropped significantly at an average rate of 80%, compared with the emissions from 2007, even as the trade grew substantially. COD and SO_2 emissions embodied in the export experienced the most considerate decline over the year, from 170874 tons in 2007 to 28529.8 tons in 2017, and from 6157 tons to 1146 tons respectively.

Moreover, data suggests that these embodied emissions take up less proportion in the total industrial emission in Guangdong between the investigated years. Figure 1 demonstrates that the embodied COD emissions accounted for 52.4% of the total COD emission in 2007, while this number sinks to 37.61% in a decade's time. The same trend applies to all three other pollutants.

Table 2 The embodied emissions in Guangdong export in 2007 and 2017

Embodied emissions in Guangdong export (t)	Year		Change in total amount (t)	Rate of change
	2007	2017		
COD	170874.02	28529.8	-142344.22	-83.30%
AN	6157.41	1146.85	-5010.56	-81.37%
SO_2	367228.16	53590.84	-313637.32	-85.41%
NO_x	313172.35	96282.7	-216889.65	-69.26%
Average			-169470.44	-79.84%

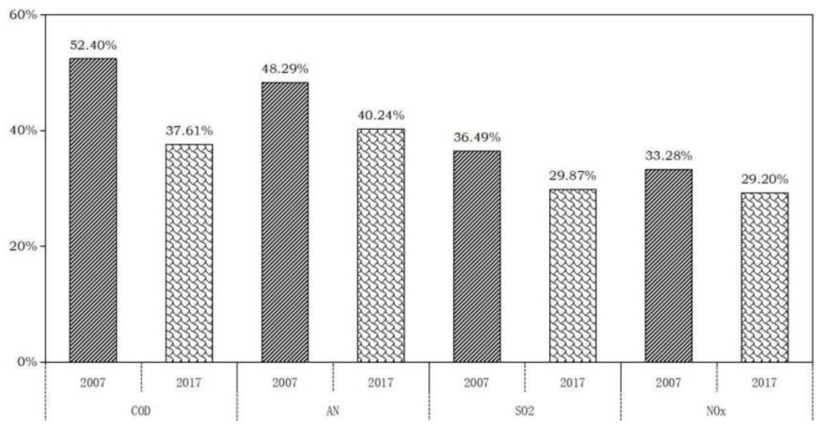

Figure 1 Proportion of embodied pollution in total pollution in 2007 and 2017

3.2 Embodied emissions change by sector

To eliminate the differences between pollutants and to better reflect emission by sector, industrial emission data is processed by dimensionless treatment before added up to represent the embodied emissions by sector. The results are demonstrated in Table 3, indicating that the embodied pollution decreased in most sectors from 2007 to 2017, with only S1 (coal mining) witnessed a slight increase in the pollution emissions and S22 (gas supply) witnessed a significant increase of 320.5 pollution equivalent value. The nine sectors with the highest pollution emissions in 2007 experienced the most dramatic decrease in embodied pollution emissions, as shown in Figure 2. S7 (clothing industry) and S9 (paper and paper products) experienced a change of more than 10000 unit of pollution equivalent value. The remaining seven other sectors experienced a similar but smaller change: S12 (nonmental mineral products), S18 (communications, computers and other electronic equipment), S15 (general and special equipment), S6 (textile), S17 (electrical machinery and equipment), S13 (metals smelting and pressing) and S11 (chemicals and chemical products).

3.3 Decomposing the embodied pollution changes in Guangdong exports by pollutants

Figure 3 and Figure 4 illustrate the results of the LMDI decomposing the influencing factors for the total change of the embodied emissions of four pollutants from 2007 to 2017. It is clear from Figure 3 that the main contributing factor to the overall clean-up in all pollutant is technical advancement. With regard to COD (Figure 4), the total change of embodied pollution, as mentioned above, decreased by 142344.22 tons. Technical advancement is the biggest contributor to such change, reducing the embodied pollution emission of COD by 157720.62 tons. Structural change also contributes, thought slightly, to the reduction in pollution emission. However, the export scale, increased the pollution emission by 28515.7 tons. The same trend applies to all three other pollutants (see Figure 4), that technical effect acts as the main contributor in reducing pollution emissions, with structural effect contributing slightly whereas the scale effect acted against the clean-up.

Table 3 Sector-level change in embodied pollution in Guangdong exports (2007-2017)

Sector Code	2007	2017	Embodied Pollution Change
S7	15963.79491	1515.39903	-14448.39588
S9	12692.76902	1682.87451	-11009.89451
S12	11721.93024	4624.04312	-7097.887126
S18	10569.4053	3260.96877	-7308.436538
S15	7486.825694	684.204282	-6802.621412
S6	6688.398306	1654.75473	-5033.643571
S17	5308.618305	1554.46368	-3754.154625
S13	5076.034141	777.09485	-4298.939291
S11	4526.701225	727.308433	-3799.392793
S8	2099.221066	450.030794	-1649.190272
S20	1743.04689	48.6638501	-1694.38304
S14	1424.059193	611.809332	-812.2498605
S19	1367.968962	165.389473	-1202.579489
S5	1339.980004	341.001302	-998.9787026
S16	742.5827774	193.553321	-549.0294565
S10	630.1432473	82.0182388	-548.1250084
S4	64.30668508	64.1291247	-0.177560369
S3	25.59496425	12.7973495	-12.7976148
S22	6.804348933	0	-6.804348933
S1	0	0.26201145	0.262011445
S2	0	0	0
S22	0	320.506985	320.5069853
S23	0	0	0

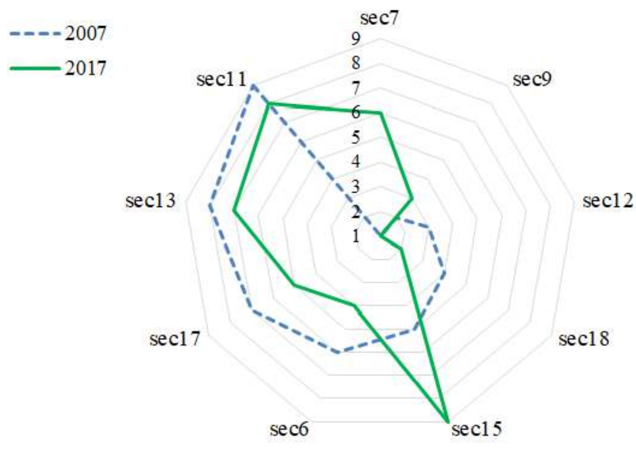

Figure 2 The nine sectors with the most significant change in embodied pollution between 2007 and 2017

3.4 Decomposing the embodied pollution changes in Guangdong exports by sectors

To better understand how different contributors affects different industrial sectors, the study proceeds with decomposition analysis of the main sectors that contribute more than 80% of the total emissions in each pollutant.

3.4.1 Contributors to embodied pollution changes of COD within the main sectors

The six main sectors that contribute together over 80% of COD emissions in Guangdong exports are: S5 (food and tobacco), S6 (textile), S7 (clothing), S9 (paper and paper products), S11 (chemicals and chemical products) and S18 (communications, computers and other electronic equipment). Results of the decomposition factors affecting in embodied COD emission in these sectors from 2007 to 2017 are presented in Figure 5. Results show that technical advancement is the driving force for the reduction in COD emission in Guangdong exports during 2007 and 2017, and S7 (clothing) and S9 (paper and paper products) are more sensitive to technical advancement than other sectors. Scale effect on the other side, puts on positive effect on embodied COD pollution change.

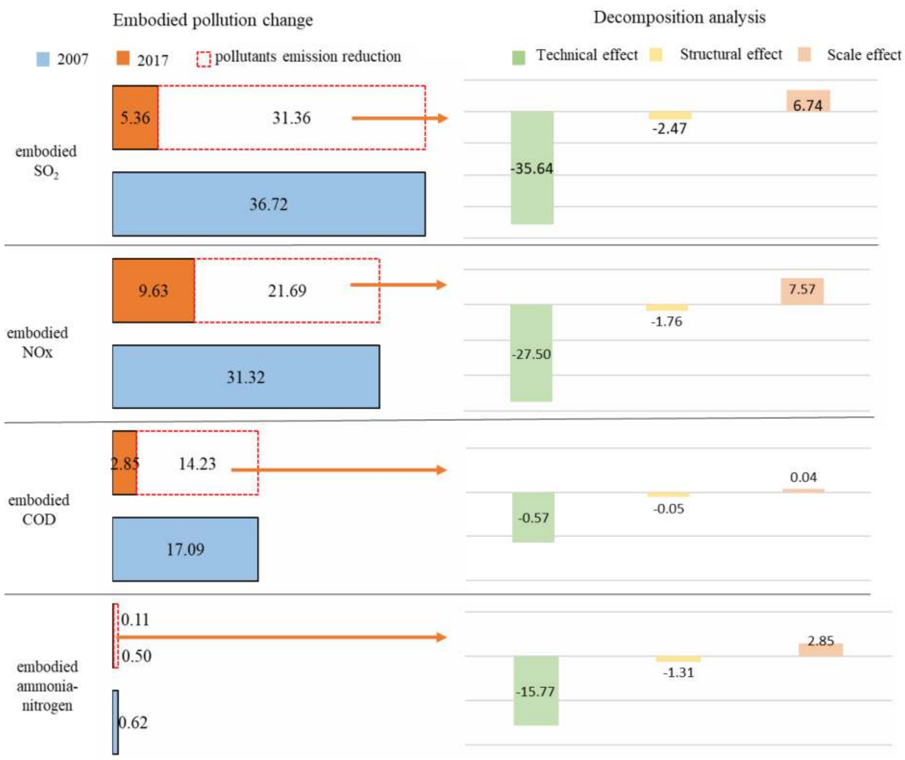

Figure 3 Embodied pollutants emission changes of Guangdong export between 2007 and 2017 and its decomposition analysis (10^4 tons)

3.4.2 Contributors to embodied pollution changes of AN within the main sectors

The above mentioned six sectors that account for the most emission of COD in the export also contribute the most to the AN emission. The contribution of these six industrial sectors to embodied ammonia nitrogen emissions of Guangdong export were 84.63% and 87.29% respectively, which accounted for an important share of the implied ammonia nitrogen emissions in export trade and showed an increasing trend. Figure 6 shows the decomposition of the effect of embodied ammonia nitrogen emissions from exports of key industries in Guangdong. Similar to the situation of implied COD emission in export, technical effect contributes most to the emission reduction, with S7 (clothing) being the most sensitive sector to technical changes, which indicates that the improvement of emission performance of the industry effectively promotes the emission reduction of embodied ammonia nitrogen in export. Structural effect, on the other hand, places an outstandingly positive effect on S18 (communications, computers and other electronic equipment), which is probably relevant to recent export policies favoring high-tech commodities. Data suggests that the proportion of S18 in the Guangdong export have grown substantially from 24% in 2007 to over 40% in 2017. With regard to scale effect, S6 (textile) and S7 (clothing) have the most significant scale effect compared with other industries, which is most probably because they remain to be the dominant traditional industry in Guangdong, with large volume of export commodities over the years between 2007 and 2017.

3.4.3 Contributors to embodied pollution changes of SO_2 within the main sectors

The eight sectors that contributed the most to the SO_2 emissions from exports in Guangdong are: S7 (clothing), S12(nonmental mineral products), S9 (paper and paper products), S18 (communications, computers and other electronic equipment), S15 (general and special machinery), S13 (metals smelting and pressing), S6 (textile) and S17 (electrical machinery and equipment). In 2007 and 2017, the contribution of the eight industrial sectors to the embodied SO_2 emissions of Guangdong exports reached the rates of 84.35% and 83.28%, respectively. The decomposition results of the effect of SO_2 emissions are shown in Figure 7. S7, though having the highest contribution rate to SO_2 emission over the years, enjoys the most substantial emission reduction, which could be mostly explained by technical effect (-51400 tons) and structural effect (-11400

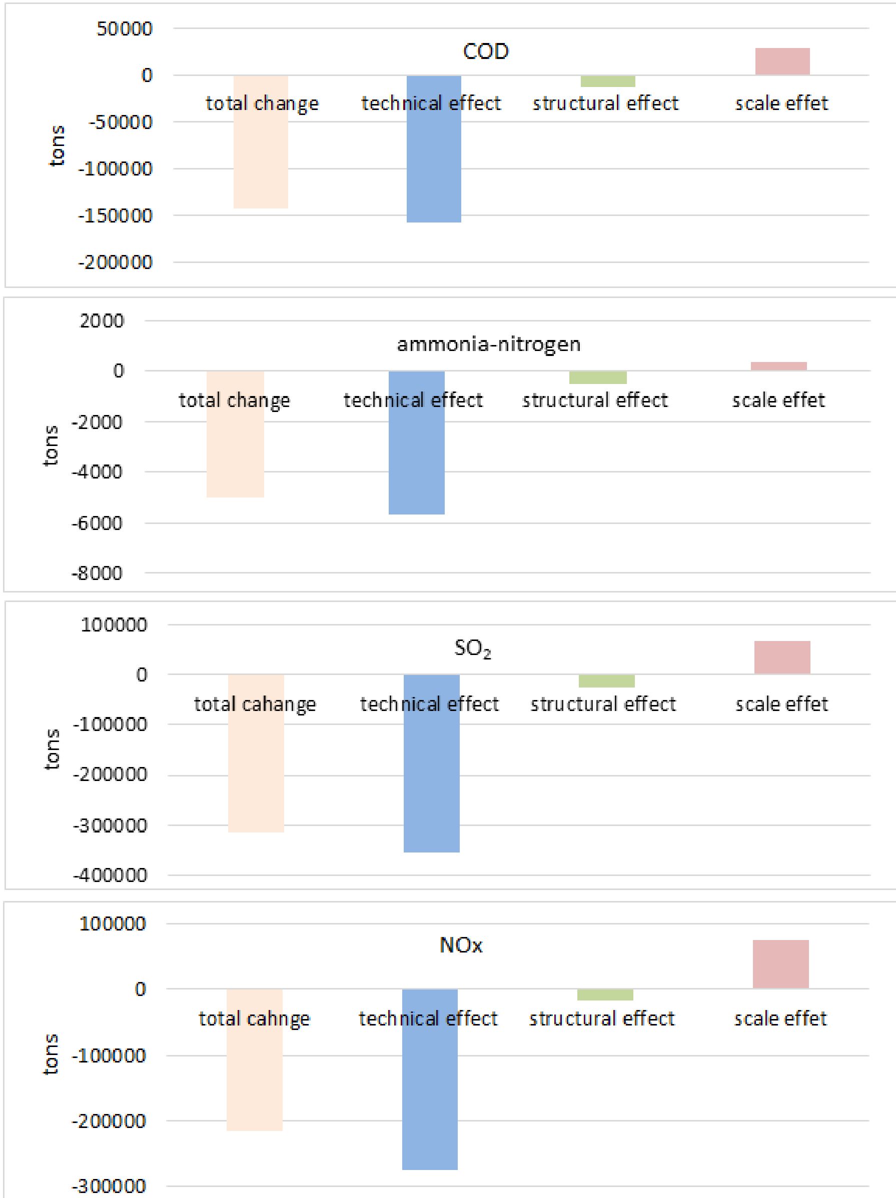

Figure 4 Contributors of the clean-up in Guangdong exports (2007-2017)

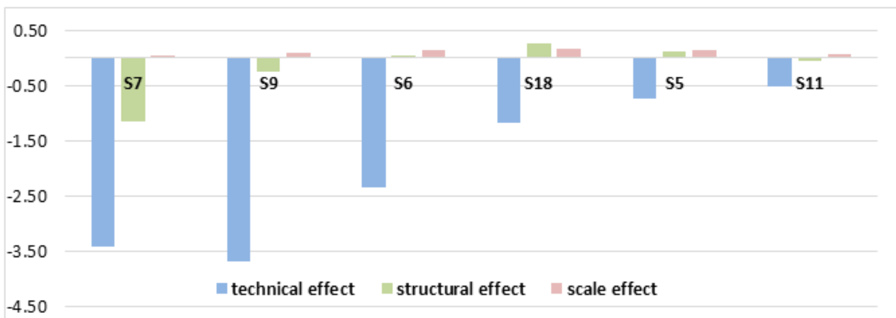

Figure 5 Contributors to COD emissions change in the main sectors of Guangdong exports from 2007 to 2017 (10^4 tons)

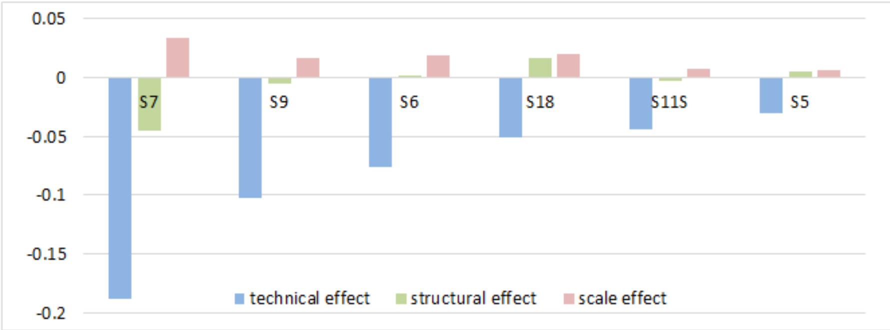

Figure 6 Contributors to AN emissions change in the main sectors of Guangdong exports from 2007 to 2017 (10^4 tons)

tons). Whereas the scale effect and structure effect of some sectors have a greater positive effect, such as S12. Stringent environmental regulations have been taken to restrict the manufacturing and exporting of high pollution products, including eliminating high pollution and high emission enterprises, rectifying "scattered pollution" industrial enterprises, and promoting industrial green recycling upgrading and transformation. As a result, the emission reduction effect of S12 (-60400 tons) is greater than the sum of scale effect and structure effect in the same period (18400 tons).

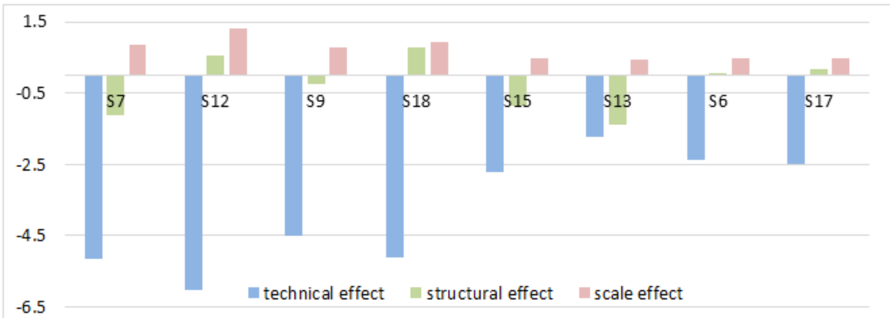

Figure 7 Contributors to SO_2 emissions change in the main sectors of Guangdong exports from 2007 to 2017 (10^4 tons)

3.4.4 Contributors to embodied pollution changes of NO_x within the main sectors

The eight industrial sectors that contributed most to the embodied NO_x emissions in the exports are: S12 (nonmental mineral products), S18 (communications, computers and other electronic equipment), S7 (clothing), S9 (paper and paper products), S15 (general and special machinery), S17 (electrical machinery and equipment), S13 (metals smelting and pressing) and S6 (textile), the contribution rates of which to the embodied NO_x emissions of Guangdong exports were at 83.12% and 84.47%, in the year of 2007 and 2017 respectively. Figure 8 shows the decomposition results of the contributors to embodied NO_x emission of main polluting industries in Guangdong exports. Similar to the three other pollutants, technical effect contributes to the emissions reduction to all sectors to a different degree, with S12 and S18 enjoys the greatest benefit from technical advancement. This could be explained by the great efforts in recent years of promoting de-nitration process in nonmental mineral industries, and technical improvements in the computer manufacturing sector. On the other hand, these two sectors also have the greatest positive effect from structural change and the scaling up. As the dominant traditional industry in Guangdong, the nonmetal mineral products industry has large export volume and high NO_x emission coefficient. The sum of scale effect and structure effect (24600 tons) is most significant among the main industries, followed by S18, with a sum of over 90000 tons.

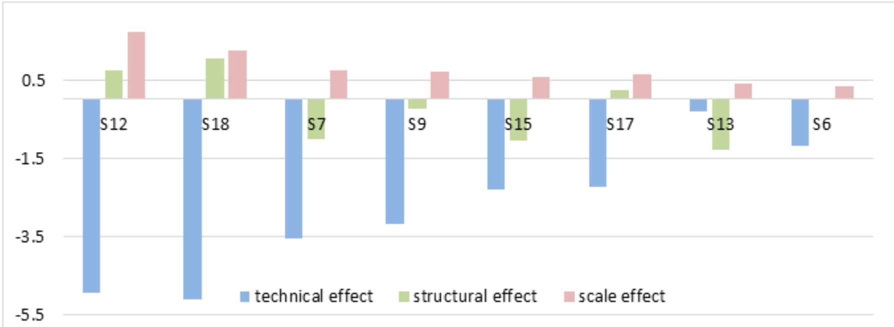

Figure 8 Contributors to NO_x emissions change in the main sectors of Guangdong exports from 2007 to 2017 (10^4 tons)

4 Conclusions and policy implication

This paper focuses on examining the change in the total pollution emissions embodied in Guangdong export, as well as the contributing reasons to such changes. We built an EIO-LMDI (Environmental Input-Output and Logarithmic Mean Divisia Index) model to conduct a structural decomposition analysis of pollution embodied in Guangdong exports, from 2007 to 2017. The results indicate that:

(1) The embodied emissions of exports in Guangdong declined exceptionally during the research period, despite the continued growth in total export.

(2) Most of such decline in emission could be explained by the technical effect, demonstrating that technological advancement is the contributing factor of the implicit pollution reduction in Guangdong exports.

(3) The export scale effect increases the embodied pollution emissions, and the industrial sectors with larger total pollution emission coefficient are more sensitive to scale factor.

(4) Although declined, the embodied emissions of exports still accounted for more than 30% of the total emission of main pollutants in Guangdong, indicating that the exports structure remained to be occupied with high pollution and resource intensive industries, such as textile, clothing, nonmetal mineral products industry, chemical industry, food and tobacco, *etc*.

In recent years, Guangdong Province has taken stringent and effective measures to readjusting and optimizing industrial structures. Guangzhou, Shenzhen, Foshan, Zhuhai and other economically active cities have vigorously promoted scientific and technological innovation and industrial transformation, which had been acting as the “booster” and “accelerator” to achieve high-quality development. The export structure has been adjusted and optimized to a certain extent. And most of these efforts have been placed on technology advancements, resulting in the increase of the proportion of high value-added products and low pollution emission products in total exports. These efforts in up-grading production technologies aligns with the governments more than 60%. And much of these declines could be explained by the technical effect. their focuses on strictly controlling the export of products from high pollution, *etc*. At the same time, it is vital to continue promoting the technical advancement and action plan for the transformation and upgrading of traditional industries, such as thermal power, textile, plastics, construction materials, and paper and paper products to drive the overall emission reduction of embodied pollution in Guangdong exports.

The measures and plans delivered by the PRD governments demonstrate possible developing routes for other big export regions and countries. The substantial decline in the embodied emission of the PRD exports indicates that technology innovations play major parts in cleaner development and that by focusing on technological advancement, it is possible to achieve remarkable achievements in pollution reduction. Accompanying the efforts in innovating production process, a commitment of facilitating the development of high-tech industries with favorable policies, such as reduction in tax, priority in approval process and fiscal support, will also contribute to a cleaner export structure.

The accounting of embodied pollution is an important filed in global environmental studies, as it assists us in understanding the true cost in international trades. In this study, we attempt to construct a calculation method to comprehensively calculate the hidden pollution in export in Guangdong. Though based on local parameters, we hold the belief that this method could be adopted by studies held in other regions.

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