Ecological Economics 164 (2019) 106340

Contents lists available at ScienceDirect

Ecological Economics

journal homepage: www.elsevier.com/locate/ecolecon

Analysis

Economic gains and environmental costs from China's exports: Regional inequality and trade heterogeneity

Zengkai Zhang[a], Yuwan Duan[b,d,*], Wei Zhang[c]

[a] College of Management and Economics, Tianjin University, Tianjin, China
[b] School of International Trade and Economics, Central University of Finance and Economics, Beijing, China
[c] State Environmental Protection Key Laboratory of Environmental Planning and Policy Simulation, Chinese Academy for Environmental Planning, Beijing, China
[d] Center for Global Economy and Sustainable Development, Central University of Finance and Economics, Beijing, China

ARTICLE INFO

Keywords:
Regional inequality
Trade heterogeneity
Processing exports
Input-output model

ABSTRACT

As the world's factory, processing exports comprise a remarkable share of China's total exports. By fully taking the special characteristics of processing trade into account, this paper comprehensively investigates the unbalanced distribution of trade-related economic benefits and environmental costs across different regions in the years of 2007 and 2012. We find a serious regional mismatch between trade-related pollutions and economic gains, with the coastal region gaining more economically but emitting less, whereas the inland regions gain less but emit more. We also conclude that trade-related value added and air pollutions would be overestimated significantly if trade heterogeneity was not correctly captured. Processing exports are cleaner but result in greater regional inequality in terms of trade-related economic gains and environmental costs, although the regional inequality induced by processing exports presented a decreasing trend over the period 2007–2012. The electricity generation sector plays a dominant role in this outcome. Coastal regions should transfer more trade-related economic gains to help sustainable development in inland regions.

1. Introduction

Since China's reform and opening up policy in 1978, China has attained impressive achievements in both international trade and economic development. However, this spectacular economic growth has not benefited its regions equally. In particular, by virtue of their geographical advantage, the coastal provinces have actively participated in global production and benefited greatly from it. The data from the World Bank show that the Gini coefficient for family income in China reached 0.42 in 2012, and regional disparities contribute significantly to China's income inequality (Xie and Zhou, 2014). To support export production in coastal regions, inland regions have provided substantial raw materials and generated abundant pollutions (Li et al., 2016). Ideally, the trade-related economic gains obtained by a region should be consistent with the environmental costs it suffered. This study explores the unbalanced distribution of trade-related economic benefits and air pollution among different regions. This issue is quite important given China's large regional income disparity and serious environmental problems.

One of the most salient features in China's international trade is the high share of processing trade. Under this trade regime, enterprises first import intermediate inputs from abroad free of duty and re-export the finished products after processing or assembly (Yang et al., 2015). In 2012, processing exports accounted for as much as 42.11% of China's total merchandise exports. Due to the strong dependence on imported products, processing exports are characterized by two typical features. First, processing exports generate much less domestic activities than ordinary exports. Therefore, a unit of processing exports always induces less value added and pollutions than a unit of ordinary exports (Chen et al., 2012; Dietzenbacher et al., 2012; Johnson and Noguera, 2012; Koopman et al., 2012). Second, the distribution of processing exports is extremely unbalanced across domestic regions, compared with ordinary exports. More specifically, firms involved in processing exports are more concentrated in the coastal provinces, which have a closer linkage with foreign countries. For instance, in 2012, the coastal provinces contributed to more than 80% of China's processing exports. The data from China's customs show that processing exports accounted for 56.9% of total exports of the south coast (please refer to Appendix A for eight regions) in 2010, while this proportion was only 9.1% in the northwest region, which is located in inland China.

Due to China's large share of processing exports, the existing literature proves that studies failing to separate processing exports from

* Corresponding author.
E-mail address: duanyuwan@cufe.edu.cn (Y. Duan).

https://doi.org/10.1016/j.ecolecon.2019.05.020
Received 5 January 2019; Received in revised form 7 April 2019; Accepted 20 May 2019
Available online 11 June 2019
0921-8009/

other productions will exaggerate the contribution of China's exports to its economic growth (Pei et al., 2012), overestimate the damage of international trade to China's environment (Dietzenbacher et al., 2012), and lead to other biased estimates or misleading conclusions (Johnson and Noguera, 2012; Koopman et al., 2012). The literature found that international trade significantly widens regional inequality, especially in developing countries (Fukuda, 2018; Gill, 2006; Meschi and Vivarelli, 2009; Zhang and Zhang, 2003). There are numerous studies on regional mismatches in trade-related pollution and economic benefits (Feng et al., 2013; Li et al., 2016; Mi et al., 2017; Wang et al., 2018; Zhang et al., 2018; Zhang and Lin, 2018). However, as far as we know, no study has considered the potential impacts of trade heterogeneity on this topic. To fill this research gap, this paper remaps the economic benefits and environmental impacts related to China's exports with a clear distinction between ordinary and processing exports. Concretely, we attempt to answer the following two questions. How does trade heterogeneity impact the estimation of the economic gains and environmental costs related to trade? Which export regime, processing exports or ordinary exports, contributes more to China's regional inequality in terms of trade-related economic gains and environmental impacts? In addition, this study also investigates the temporal change in the unequal exchange of trade-related economic benefits and air pollutions among China's main regions over the period 2007–2012.

This paper is based on studies that emphasize the importance of separating processing exports in input-output (IO) tables when investigating the environmental consequence of international trade (Dietzenbacher et al., 2012; Jiang et al., 2017, 2016, 2015; Su et al., 2013; Xia et al., 2015). Among them, most of the studies take China as a homogeneous entity and therefore ignore regional heterogeneity. The only exemption is Jiang et al.'s (2017) study, which has explored the contribution of trade heterogeneity to China's regional disparity of energy intensity in 2007 by using the interregional input-output tables that separate the production of processing exports. However, Jiang et al.'s (2017) study focused exclusively on energy, which is very different from emissions. As an important complement to the existing literature, this paper aims to investigate the economic and environmental effects of exports in 2007 and 2012, by taking full consideration of regional and trade heterogeneity. Moreover, this paper focuses on three types of air pollution SO_2, NOx, and particulate matter (PM). Here, PM in China's environmental statistics comprises soot and dust, which both contain total suspended particulates (TSP), PM_{10} and $PM_{2.5}$. We aggregate air pollution emissions into atmospheric pollutant equivalents (APE), according to each pollution's environmental and health impacts.

The paper is organized into four sections. Section 2 describes the methodology. Section 3 presents the empirical results. Conclusions are presented in Section 4.

2. Methodology and data

This study adopts a unique interregional input-output table proposed by Duan et al. (2014), which separates the input structure of processing exports from other ordinary productions (hereafter the IRIOP table). The general structure of the IRIOP table is shown in Table 1, which includes *n* regions, and each region has *m* sectors.

We start with a description of the main variables. *Z* represents intermediate input matrix, *m* represents import vector, *e* represents export vector, *y* represents final demand except for exports, *v* represents value added vector, *x* represents output vector, *f* represents pollution vector. The superscripts o and p represent ordinary production and processing exports. The subscripts r and s represent two regions. For example, Z_{rs}^{op} denotes the deliveries of intermediate products from region r to region s for processing exports. We could obtain the ordinary inter-regional input-output table through aggregating over the production types in each sector within each region. We define $x = \begin{bmatrix} x_1^p \\ x_1^o \\ \vdots \\ x_n^p \\ x_n^o \end{bmatrix}$,

$Z = \begin{bmatrix} 0 & 0 & \cdots & 0 & 0 \\ Z_{11}^{op} & Z_{11}^{oo} & \cdots & Z_{1n}^{op} & Z_{1n}^{oo} \\ \vdots & \vdots & \ddots & \vdots & \vdots \\ 0 & 0 & \cdots & 0 & 0 \\ Z_{n1}^{op} & Z_{n1}^{oo} & \cdots & Z_{nn}^{op} & Z_{nn}^{oo} \end{bmatrix}$, $Y = \begin{bmatrix} 0 & \cdots & 0 \\ y_{11}^o & \cdots & y_{1n}^o \\ \vdots & \ddots & \vdots \\ 0 & \cdots & 0 \\ y_{n1}^o & \cdots & y_{nn}^o \end{bmatrix}$, $e^p = \begin{bmatrix} e_1^p \\ 0 \\ \vdots \\ e_n^p \\ 0 \end{bmatrix}$, $e^o = \begin{bmatrix} 0 \\ e_1^o \\ \vdots \\ 0 \\ e_n^o \end{bmatrix}$,

$e = \begin{bmatrix} e_1^p \\ e_1^o \\ \vdots \\ e_n^p \\ e_n^o \end{bmatrix}$, $v = [v_1^p \ v_1^o \ \cdots \ v_n^p \ v_n^o]$, $F = [f_1^p \ f_1^o \ \cdots \ f_n^p \ f_n^o]$. The gross output production and use balance can be written as:

$$x = Zu + Yw + e \tag{1}$$

where $u = (1, \cdots, 1)_{2mn \times 1}$ and $w = (1, \cdots, 1)_{n \times 1}$. Zu is row sum of the 2mn by 2mn matrix Z, and Yw is row sum of the n by 1 matrix Y. $A = Z(\hat{x})^{-1}$ is the intermediate input coefficient matrix. $\hat{x}$ indicates the diagonalization of the gross output vector x. The Leontief inverse matrix is $B = (I - A)^{-1}$. Eq. (1) can be expressed as:

$$x = (I - A)^{-1}(Yw + e) = B(Yw + e) \tag{2}$$

$F = \hat{f}\,(\hat{x})^{-1}$ is the pollution coefficient matrix, $V = \hat{v}\,(\hat{x})^{-1}$ is the value added coefficient matrix. Then, emissions (*ex*) and value added (*vx*) embodied in total exports are

$$ex = FBe^o + FBe^p \tag{3}$$

$$vx = VBe^o + VBe^p \tag{4}$$

From the regional perspective, emissions in region r induced by normal and processing exports of region s are ex_{rs}^{o} and ex_{rs}^{p}, where r, s = 1, ⋯, n. Similarly, value added in region r induced by normal and processing exports of region s are vx_{rs}^{o} and vx_{rs}^{p}. The disproportion of trade-related emissions and value added between two different regions r and s(r ≠ s) is represented by an environmental (APE) and economic (GDP) justice index (*ag* index) shown below:

$$ag_{rs}^{h} = \frac{ex_{rs}^{h} / \sum_{r,s} ex_{rs}^{h}}{vx_{rs}^{h} / \sum_{r,s} vx_{rs}^{h}}; \quad h = o, p \tag{5}$$

where ag_{rs}^{o} and ag_{rs}^{p} refer to the share of total trade-related pollution occurred in region r in exchange for the share of total trade-related economic gains obtained by region r through domestic production networks to support the ordinary and processing exports in region s. ag_{rs}^{o} and ag_{rs}^{p} are ratios of two ratios. If ag_{rs}^{o} and ag_{rs}^{p} are greater than 1, region r received relatively greater share of trade-related environmental costs and obtained relatively less share of trade-related economic gains, and vice versa. If there is no regional inequality, ag_{rs}^{o} and ag_{rs}^{p} would be equal to 1.

Besides the IRIOP tables that we used in this paper, there are other input-output databases providing information on processing trade of China. For example, Chen et al. (2012) proposed the so-called DPN IO table of China (or national tripartite IO table), which distinguishes production for domestic use (D), production of processing exports (P), and production for domestic use (N) in national IO tables. The OECD Inter-Country Input-Output (ICIO) database[1] also distinguishes processing trade for China and Mexico (OECD, 2015). Based on the DPN IO table and the World Input-Output Database, Chen et al. (2018) construct another version of world input-output table that distinguishes China's production of processing exports from other production. A

[1] Sources: https://www.oecd.org/sti/ind/inter-country-input-output-tables.htm.

Table 1
The structure of China's IRIOP table.

		Intermediate input					Final use					Gross output or imports
		Region 1		…	Region n		Region 1	…	Region n	Exports		
		P	O		P	O						
Region 1	Processing exports (P)	0	0	…	0	0	0	…	0	$\mathbf{e}^p{}_1$		$\mathbf{x}^p{}_1$
	Ordinary production (O)	$\mathbf{Z}^{op}{}_{11}$	$\mathbf{Z}^{oo}$ 11	…	$\mathbf{Z}^{op}{}_{1n}$	$\mathbf{Z}^{oo}{}_{1n}$	$\mathbf{y}^o{}_{11}$	…	$\mathbf{y}^o{}_{1\mathrm{n}}$	$\mathbf{e}^o{}_1$		$\mathbf{x}^o{}_1$
…		…	…	…	…	…	…	…	…	…		…
Region n	Processing exports (P)	0	0	…	0	0	0	…	0	$\mathbf{e}^p{}_{\mathrm{n}}$		$\mathbf{x}^p{}_{\mathrm{n}}$
	Ordinary production (O)	$\mathbf{Z}^{op}{}_{n1}$	$\mathbf{Z}^{oo}{}_{n1}$	…	$\mathbf{Z}^{op}{}_{nn}$	$\mathbf{Z}^{oo}{}_{nn}$	$\mathbf{y}^o{}_{n1}$	…	$\mathbf{y}^o{}_{\mathrm{nn}}$	$\mathbf{e}^o{}_{\mathrm{n}}$		$\mathbf{x}o{}_{\mathrm{n}}$
Imports		$\mathbf{m}^p{}_1$	$\mathbf{m}^o{}_1$	…	$\mathbf{m}^p{}_n$	$\mathbf{m}^o{}_n$	$\mathbf{m}y{}_1$	…	$\mathbf{m}y{}_{\mathrm{n}}$	0		$\mathbf{m}$
Value added		$\mathbf{v}^p{}_1$	$\mathbf{v}^o{}_1$	…	$\mathbf{v}^p{}_n$	$\mathbf{v}^o{}_n$						
Gross output		$(\mathbf{x}p{}_1)'$	$(\mathbf{x}^o{}_1)'$	…	$(\mathbf{x}^p{}_n)'$	$(\mathbf{x}^o{}_n)'$						
Pollutions		$\mathbf{f}^p{}_1$	$\mathbf{f}^o{}_1$	…	$\mathbf{f}^p{}_n$	$\mathbf{f}^o{}_n$						

major advantage of these two databases lies in their detailed information on the international economic linkage between different countries. However, these two databases take China as a homogeneous entity, and therefore ignore the regional heterogeneity within China. This paper focuses on the regional inequality induced by exports, rather than tracing the source country and destination country. Therefore, we adopt a unique interregional input-output table proposed by Duan et al. (2014), which separates the input structure of processing exports from other productions for eight regions in China.

Duan et al. (2014) described the compilation process of the IRIOP table explicitly. There are several data sources including the Chinese non-competitive interregional IO table compiled by the China State Information Center (SIC) and the National Bureau of Statistics of China (NBS); the national tripartite IO table distinguishing the productions for processing exports, ordinary exports and domestic use, which is compiled by the Chinese Academy of Sciences (CAS) and the NBS (Chen et al., 2012); the international trade statistics by trade regime, commodity and 31 provinces provided by China's Customs; and the regional economic accounts, including value added, final consumption, fixed capital formation, and inventory change at sectoral. The IRIOP tables contain 17 sectors (please see Appendix A) and include eight regions: the northeast region (NE), the northern municipality region (NM), the north coast (NC), the east coast (EC), the south coast (SC), the central region (CR), the northwest region (NW), and the southwest region (SW). The classification of China's eight regions is presented in Appendix B. The eight regions are divided into coastal (northeast region, central region, northwest region, and southwest region) and inland regions (northern municipality, north coast, east coast, and south coast).

The air pollution data are obtained from the China Environmental Statistics database (MEP, 2008; MEP, 2013), which is the most authoritative survey data source on pollutions in China thus far. To obtain the emissions by region and by sector, to be consistent with the IRIP table, we first aggregate pollutions at the firm level to the sector level in the eight regions. Sectoral pollution is further disaggregated into two parts, which are usually based on the direct energy inputs of ordinary production and processing exports. The IRIOP table has a relatively aggregated sector classification, with only 17 sectors and fails to clearly indicate the energy inputs of different sectors in different regions. Therefore we distinguish the emissions of processing exports and ordinary production by using the national tripartite table. In more detail, China's General Administration of Customs (CGAC) routinely collects detailed data on trade, disaggregated by commodity, by trade patterns, and by types of enterprises. The NBS conduct special input-output surveys on enterprise manufacturing costs and materials-purchasing sources. Based on these unpublished data and other data, the CAS constructs the national tripartite IO table in 2012, which provides the domestic and foreign direct six-type energy inputs for ordinary and processing exports. Assuming that ordinary production and production for processing exports face the same energy price and emission coefficient, we could split the sector emissions into emissions directly emitted by ordinary production and by processing exports at the national level. The results show that direct emissions of the processing exports account for an extremely small share (0.14% for soot, 0.06% for NOx, and 0.14% for SO_2) of the gross emissions. Instead, indirect emissions play a dominant role in emissions induced by processing exports. It has a limited impact on the calculation results to differentiate the direct pollution emissions coefficients of processing exports in eight regions. Therefore, we assume that emission coefficients across regions are the same for the same product type within each sector, and further split sector emissions in eight regions into ordinary production and processing exports. To comprehensively reflect the environmental cost of China's exports, this study constructs the APE *index* by aggregating four pollutants by their environmental and health impacts. This method has been adopted by China's Ministry of Environmental Protection (MEP) to define "pollution equivalent" since 1982 (Yang and Wang, 1998). In this study, the conversion coefficients for SO_2, NOx, soot and dust are 0.95, 0.95, 2.18 and 4, respectively.[2]

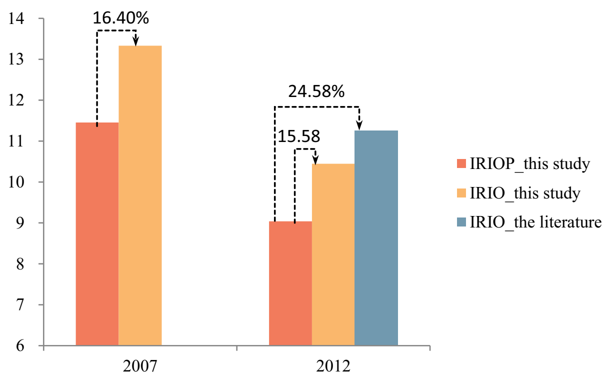
3. Empirical results

Before presenting our empirical results, we first briefly overview the feature of China's processing exports, which is important to further understand the empirical results. Processing exports not only occupied a great share of China's gross exports but also presented a feature of spatial agglomeration and sectoral concentration (see Appendix C). In 2012, for example, China's processing exports accounted for as much as 39.54% of the gross exports. In particular, the east and south coastal regions contributed as much as 75.65% of China's total processing exports. By sector, it is proven that the exports of electronic products dominate the processing exports, with a share of 58.17% of total processing exports in 2012. The regional heterogeneity of the distribution of processing exports determines that it plays important roles in the variations in the economic and environmental impacts of exports across regions.

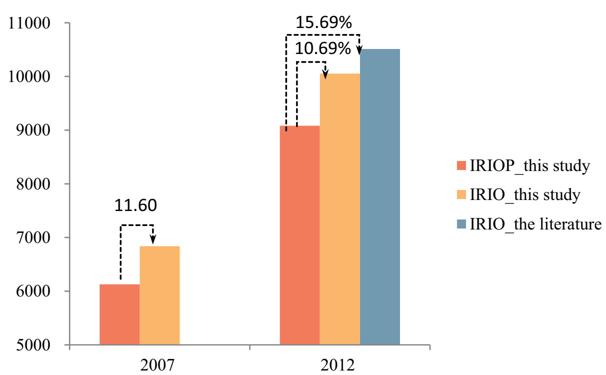
3.1. Overestimation of the trade-related APE and value added

This section evaluates the effect of trade heterogeneity on the estimation of regional value added and APE embodied in China's exports. To this end, we first calculate the trade-related economic benefits and environmental impacts by utilizing the special IRIOP tables. As a comparison, we also re-calculate the results by using the traditional

[2] State Development Planning Commission; Ministry of Finance; State Environmental Protection Administration; State Economic and Trade Commission, Measures for Levy Standard on Pollutant Discharge Fee. (In Chinese).



a) APE embodied in China's exports in 2007 and 2012 (million tons)



b) Value added embodied in China's exports in 2007 and 2012 (billion RMB)

Fig. 1. Value added and APE embodied in China's exports in 2007 and 2012.

interregional input-output (IRIO) tables (the structure are presented in Appendix D) that are obtained by aggregating sectors for ordinary production and processing exports. The empirical results are presented in Fig. 1.

Based on the IRIOP table, the APE embodied in China's exports was 11.45 million tons in 2007 and 9.04 million tons in 2012. Meanwhile, the value added embodied in China's exports was 6126.70 billion RMB in 2007 and 9081.20 billion RMB in 2012. In contrast, the results from the traditional IRIO table show that APE embodied in China's exports reached 13.33 million tons in 2007 and 10.45 million tons in 2012. Meanwhile, trade-related value added from the traditional IRIO table reached 6837.66 billion RMB in 2007 and 10,052.14 billion RMB in 2012. Zhang et al. (2018) calculated APE and value added embodied in China's exports in 2012 based on another IRIO table that divided China into 30 regions. They found that APE and value added embodied in China's exports in 2012 reached 11.26 million tons and 10,506.00 billion RMB, respectively. The difference may be due to the sectoral and regional aggregation levels of these two studies.

These figures clearly indicate that trade-related APE would be seriously overestimated by 16.40% in 2007 and 15.58% in 2012 if trade heterogeneity were not properly taken into account. Instead, trade-related value added would be overestimated by 11.60% in 2007 and 10.69% in 2012. Clearly, trade heterogeneity will cause a larger bias in the calculation of trade-related APE. Over time, however, our empirical results also show that the impact of trade heterogeneity decreased. The possible reason is the remarkable decreasing share of processing exports in China's gross exports (Dietzenbacher et al., 2012). However, the share of processing exports is still sufficiently large to significantly impact the economic benefits and environmental costs of international trade.

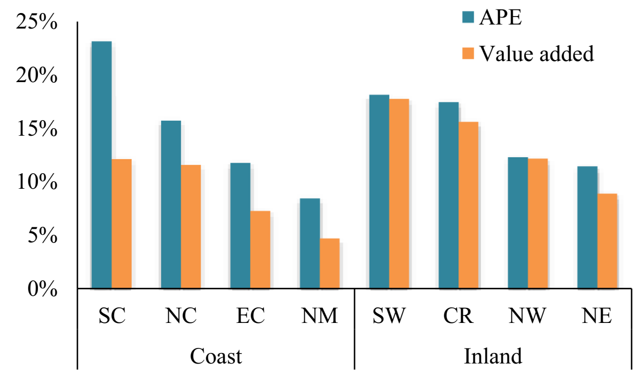


Fig. 2. Overestimation of regional APE and value added embodied in exports.

The overestimation value on regional APE and value added embodied in China's exports are presented in Fig. 2, which clearly demonstrates that the traditional IRIO table will highly overestimate both the trade-related APE and value added in all regions but to different degrees. In particular, the degree of the bias in trade-related APE is up to 23.12% in the south coast region, much larger than that in other regions. The southwest region's trade-related value added is overestimated by 17.74%. To be clear, we further group the eight regions into coastal regions (NM, NC, EC, and SC) and inland regions (NE, CR, NW, and SW). We observe that the coastal region has a greater gap between the degree of overestimation on the trade-related environmental impacts and economic gains than the inland region. If trade heterogeneity were not taken into account, the coastal region's value added per unit of exported APE would be more significantly underestimated. The evaluation of the regional unbalanced distribution of trade-related environmental costs and economic gains would be biased, which is mainly due to the different characteristics of ordinary and processing exports and will be presented in the following section.

3.2. Processing exports are cleaner but contribute more to regional inequality

This section traces the regional pollutions, measured by APE, and economic gains, measured by value added, induced by China's ordinary and processing exports in 2012. The calculation results are presented in Table 2. Our results indicate a cleaner production of processing exports than that of ordinary exports. In 2012, processing exports accounted for 39.54% of China's gross exports, but only contributed 23.52% of the domestic value added generated by the total exports. This result coincides with the existing literature that concludes that less value added is generated per unit of processing exports than ordinary exports. Our results further indicate that processing exports also generated fewer emissions than equivalent ordinary exports in 2012. APE induced by processing exports makes up only 17.31% of the gross trade-related APE. Consequently, processing exports correspond to a smaller APE intensity, measured by the ratio of trade-related APE to trade-related value added, than ordinary exports. In this respect, processing exports are cleaner than ordinary exports (Table 2).

Trade-related economic gains and environmental costs are unequally distributed among different regions. Coastal regions benefit most from China's exports in terms of value added. In 2012, the national exports generated 2571.26 billion RMB value added for the east coast, which is 28.31% of China's national value added induced by exports. The south coast follows with a share of 24.38%. Instead, the inland regions obtain less value added but generate a large share on trade-related APE. For instance, the northwest region received only 5.43% of China's exported value added but generated 15.07% of China's exported APE. Although the central and western regions are net recipients of the interregional value added spillover induced by exports (Pei et al.,

Table 2
Regional share of APE and value added induced by China's exports (%).

	Exported value added		Sum	Exported APE		Sum
	Processing exports	Ordinary exports		Processing exports	Ordinary exports	
Northeast	1.42	5.25	6.66	1.53	7.51	9.03
Northern municipalities	1.00	5.26	6.27	0.35	2.30	2.65
North coast	2.48	10.17	12.65	2.92	13.52	16.44
East coast	7.90	20.41	28.31	3.75	13.58	17.32
South coast	6.96	17.41	24.38	1.81	10.78	12.58
Central regions	2.31	8.56	10.87	3.37	13.87	17.24
Northwest	0.80	4.63	5.43	2.43	12.65	15.07
Southwest	0.64	4.79	5.43	1.16	8.48	9.65
Northeast	23.52	76.48	100.00	17.31	82.69	100.00

2015), these two regions obtain a smaller share of trade-related economic gains than the coastal region. China's resources are mainly located in the inland provinces, which generate emissions to support the production of exported products in coastal regions. A large volume of the value added induced by exports is obtained by the coastal region. Inland regions take the responsibility of export-related pollutions but do not receive proportional benefits.

Further evidence shows that the regional mismatch between trade-related value added and APE occurs for both ordinary and processing exports. In more detail, the northern municipalities, east coast, and south coast correspond to a greater share of trade-related value added than the share of APE for both ordinary and processing exports. For instance, the east coast obtained 26.69% of the national value added induced by ordinary exports in 2012. However, it emitted only 16.42% of APE generated for the production of ordinary exports. For processing exports, the east coastal region obtained 33.60% of trade-related value added in 2012. However, it generated only 21.64% of APE induced by processing exports.

The above analyses the regional mismatch of trade-related economic benefits and environmental impacts from a regional perspective. This section further provides a more detailed discussion on trade-related environmental and economic justice (*ag* index) from the bilateral perspective (the bilateral flows of value added and APE to support regional exports are presented in Appendices E and F). The calculation results are presented in Table 3.

Each row describes a certain region's *ag* index to produce each region's exports. For instance, Table 3.a shows that the *ag* index for supply chains from the northeast region to the northern municipalities is 1.48, which means that the share of total trade-related pollution occurring in the northeast region is 1.48 times the share of total trade-related economic gains obtained by the northeast region through domestic production networks to support the ordinary exports in northern municipalities. According to Table 3, for both ordinary and processing exports, the average *ag*s of the northern municipalities, east coastal, and south coastal regions are smaller than 1, whereas the average *ag*s of the other five regions are greater than 1. This result indicates that inland regions emit a relatively greater share of trade-related APE and obtain fewer share of trade-related value added. To put it differently, the inland regions always gain less economically but suffer more emissions from international trade, compared to the coastal regions. This outcome can be explained by the lower emission intensity and higher share of processing exports in coastal provinces, which occupy a large share of the economic benefits induced by exports.

In the column direction, Table 3 presents the AG index of each region that is related to a certain region's exports. The results indicate that inland regions' exports correspond to a greater *ag* index than that of coastal regions. For instance, the exports of the northwest region correspond to the greatest average *ag* index for both ordinary and processing exports. Meanwhile, the average *ag* index of exports of the northern municipalities and south coast are smaller than 1. This result means that the exports of these two regions generate a great share of value added embodied in China's gross exports relative to the share of

Table 3
The matrix of the *ag* index among the eight regions.

Emitter	Exporter								
	NE	NM	NC	EC	SC	CR	NW	SW	Average
a) Ordinary exports									
Northeast	1.33	1.48	1.37	1.27	1.21	1.35	1.25	1.33	1.32
Northern municipalities	0.56	0.36	0.78	0.43	0.54	0.53	0.55	0.61	0.40
North coast	1.18	1.40	1.17	1.57	1.42	1.48	1.34	1.36	1.23
East coast	0.59	0.59	0.55	0.61	0.68	0.66	0.65	0.66	0.62
South coast	0.67	0.76	0.75	0.70	0.56	0.76	0.73	0.64	0.57
Central regions	1.54	2.22	2.08	1.52	1.47	1.40	1.60	1.51	1.50
Northwest	3.00	3.82	2.80	2.27	2.64	2.77	2.43	3.07	2.53
Southwest	1.64	1.96	1.95	1.77	1.71	2.02	1.93	1.57	1.64
Average	1.33	0.69	1.22	0.86	0.74	1.39	2.09	1.53	
b) Processing exports									
Northeast	1.31	2.17	2.20	2.00	1.86	2.05	1.91	2.24	1.47
Northern municipalities	0.56	0.33	1.31	0.64	0.77	0.65	0.69	0.99	0.47
North coast	2.04	1.93	1.40	2.49	2.16	2.07	2.28	2.53	1.60
East coast	0.84	0.86	0.85	0.63	0.98	0.90	0.87	0.91	0.64
South coast	0.77	0.85	1.05	1.03	0.32	0.94	0.88	1.06	0.35
Central regions	2.24	2.89	3.14	2.42	2.24	1.15	2.36	2.68	1.98
Northwest	4.46	5.23	4.14	3.69	4.12	4.12	5.81	5.51	4.10
Southwest	2.29	2.74	3.04	2.77	2.69	2.84	2.29	1.75	2.46
Average	1.43	0.87	1.55	1.07	0.60	1.25	5.06	1.75	

APE. In other words, the exports of coastal provinces tend to be cleaner than those of inland provinces. This fact is mainly due to the lower pollution intensity of these coastal provinces.

A further comparison between Table 3.a and b can underscore the difference in processing exports and ordinary exports in terms of the *ag* index. Clearly, processing exports show a greater *ag* index than ordinary exports, which means that processing exports result in a more serious mismatch of economic benefits and environmental impacts. As previously mentioned, only a few stages of the production of processing exports are located in China. These production stages tend to be labour-intensive because of China's low labour cost. Electricity becomes a primary intermediate input for the production of processing exports. Inland provinces are China's most important electricity generation bases. Inland regions emit a great volume of pollution to produce the electricity transferred to support the production of processing exports in coastal provinces. However, they earn little value added because the revenue from electricity-generation firms is transferred to the corporate headquarters, which are mainly located in coastal provinces. Therefore, processing exports may face more serious regional mismatches of trade-related pollutants and economic benefits.

3.3. The changing trend in regional inequality induced by exports

Over recent years, China has experienced significant changes in export structure. For instance, processing exports accounted for a smaller share in the gross exports. Meanwhile, China adopted several trade-related environmental regulations to restrain pollution-intensive exports. Then, the question arises: how does the regional inequality induced by exports change over time? Answering this question has policy implications for future trade and environmental regulations.

According to Eqs. (3) and (4), we find that China has obtained greater economic benefits from international trade. Ordinary exports correspond to a greater growth rate over the period 2007–2012. The value added embodied in China's ordinary exports has increased from 4449.12 billion RMB to 6945.23 billion RMB (or by 56.10%). Meanwhile, the national value added induced by China's processing exports has increased from 1677.58 billion RMB to 2135.97 billion RMB (or by 27.32%). More importantly, with the obvious decrease in pollution intensity, both ordinary and processing exports have become cleaner in this period. The APE embodied in China's ordinary exports has decreased from 9346.32 thousand tons to 7473.57 thousand tons (or by 20.04%). The APE embodied in China's processing exports has decreased from 2107.92 thousand tons to 1564.49 thousand tons (or by 25.78%). The pollution intensity of processing exports has decreased much less than that of ordinary exports. This result may be due to the dominant role of developed countries in the global value chain. Although China has gradually restricted the processing exports of pollution-intensive products over the last decades, the developed countries own a relatively greater controlling power over global production chains. It is much more difficult for China to change the production stages for processing exports. This study further discusses the changing trends of the regional distribution of trade-related value added and APE. The results are presented in Table 4.

Table 4 shows that the mismatch of trade-related economic benefits and environmental impacts between coastal and inland regions became more serious for ordinary exports over time. For ordinary exports, the share of trade-related value added obtained by inland regions decreased from 31.20% to 30.36%. In contrast, the share of trade-related APE emitted by inland regions increased from 50.61% to 51.41%. Obviously, the result indicates that the regional unbalanced distribution of trade-related value added and APE becomes more serious over the period 2007–2012. In more detail, the northwest region obtained only 6.77% of the value added but suffered 14.03% of the environmental impacts induced by ordinary exports in 2007, with an *ag* index of 2.07. The *ag* index of the northwest region even further increased to 2.53 in 2012 because it obtained less (6.05%) value added but suffered a greater share (15.03%) of emissions from ordinary exports. Moreover, the *ag* index values of northern municipalities and the northeast region also increased obviously over the period 2007–2012. Meanwhile, some coastal regions, such as the south coastal region, experienced a sharp decrease (−18.07%) in the *ag* index. All this evidence proves that the mismatch of trade-related economic benefits and environmental impacts across regions from ordinary exports become worse over time.

The results also indicate a decreasing trend in the regional unbalanced distribution of trade-related value added and APE for processing exports over the period 2007–2012. The share of value added embodied in processing exports obtained by inland regions increases more quickly than the share of APE emitted by inland regions. The trade-related value added obtained by inland regions increased from 16.71% to 21.99%, and the trade-related APE emitted by inland regions increased from 46.43% to 49.02%. The *ag* index for the inland region decreased from 2.78 to 2.23. With the development of domestic production networks, inland regions have more opportunity to be involved in global value chains. Inland provinces could obtain a relatively greater share of trade-related value added. The coastal regions, such as the south coastal, east coastal and northern municipalities, transferred more trade-related value added to inland regions. From a regional perspective, the *ag* index values for the four inland regions all decreased obviously over the studied period. For instance, the decrease in the *ag* index of the southwest region and the central region reached as much as −31.01% and −28.47%, respectively. These two regions obtained a greater share of value added embodied in processing exports and emitted a lesser share of APE induced by processing exports. All of these findings indicate that the unbalanced distribution of value added and APE embodied in processing exports becomes less serious.

The trade patterns and pollution intensity in China have changed significantly in recent years. To see their effect on China's environment in recent years, we further update the export data and pollution intensity to 2013–2015, and re-calculate the trade-related emissions and value added gains.

The raw export data come from China's Customs Statistics, which provides the annual export values from each province. The data are not only by commodity (at 8-digit level under the Harmonized Commodity Description and Coding System, i.e. HS for short), but also by trade regime (e.g., P&A trade, PIM trade, and ordinary trade). The HS 8-digit data are further aggregated using the NBS concordance table. This yields the trade data classified by IO 17 sector. It is found that the share of processing exports in China's gross exports decreased by 16.77% over the period 2012–2015. From regional perspective, the share of processing exports in coastal region's exports decreased obviously. For instance, the share in the South coastal region had decreased by 22.26%.

The provincial pollution data are obtained from China Statistical Yearbook. From national perspective, the volume of NOx and SO_2 decreased obviously over this period, while the volume of soot increased obviously. We assume that the changes in a region's sectoral carbon intensity are identical and use the degree of changes in provincial pollution intensity to estimate the sectoral pollution intensity. Based on the updated region-sector-specific export flows and the pollution coefficients, we finally investigate the environmental effect of China's exports for recent years by assuming that the production structure in IRIOP tables always keeps its 2012 level. The changes in *ag* index of two coastal regions and two inland regions are presented in Fig. 3.

The results show that the *ag* index of the south coast region and the east coast region had decreased over the period of 2012–2015. On the contrary, the *ag* index of the central region and the northeast region had obviously increased during this period. As a consequence, the mismatch of trade-related economic benefits and environmental impacts between coastal and inland regions become more serious during this period. This condition is mainly due to the change in regional pollution coefficient. The pollution coefficient of the coastal region decreased much more obviously than that of the inland region. The coastal regions correspond

Table 4
Changes of value added and APE embodied in exports in 2007 and 2012.

	2007			2012			Change in *ag* index (%)
	GDP (%)	APE (%)	*ag*	GDP (%)	APE (%)	*ag*	
a) Ordinary exports							
Northeast	6.54	7.61	1.16	6.86	9.08	1.32	13.82
Northern municipalities	8.31	2.86	0.34	6.88	2.79	0.4	17.62
North coast	13.69	17.70	1.29	13.29	16.35	1.23	−4.83
East coast	29.39	17.13	0.58	26.69	16.42	0.62	5.56
South coast	17.40	12.16	0.7	22.77	13.03	0.57	−18.07
Central region	12.35	19.16	1.55	11.19	16.78	1.5	−3.34
Northwest	6.77	14.03	2.07	6.05	15.30	2.53	22.01
Southwest	5.54	9.37	1.69	6.26	10.26	1.64	−3.10
Sum	100.00	100.00		100.00	100.00		
b) Processing exports							
Northeast	4.30	6.58	1.53	6.02	8.83	1.47	−4.10
Northern municipalities	5.20	2.11	0.41	4.26	2.01	0.47	16.09
North coast	8.56	15.61	1.82	10.56	16.90	1.6	−12.20
East coast	36.61	19.71	0.54	33.60	21.64	0.64	19.64
South coast	32.92	16.14	0.49	29.60	10.44	0.35	−28.05
Central region	7.27	20.13	2.77	9.82	19.45	1.98	−28.47
Northwest	2.53	10.40	4.12	3.42	14.02	4.1	−0.42
Southwest	2.61	9.32	3.57	2.73	6.73	2.46	−31.01
Sum	100.00	100.00		100.00	100.00		

Notes: column (4) = column (3)/column (2); column (7) = column (6)/column (5); and column (8) = column (7)/column (4).

to smaller shares of pollutions induced by exports. China has been adjusting the export structure over the recent years, and the share of processing exports, which corresponds to greater regional inequality, decreased obviously. In order to investigate the environmental effect of changing export patterns, we further conduct another scenario analysis in which only the region-sector-specific export flows changed as they actually did while all others kept their 2012 levels. We found that the *ag* index of the southwest region, the central region, and the northeast region first decreased and reached a low point in 2014. This indicates that the mismatch of trade-related economic benefits and environmental impacts for these three regions has been alleviated over this period. In 2015, however, China's export value fell obviously, which draw the attention of the government back to export growth. As a consequence, the *ag* index of these three regions increased again.

3.4. Sectoral analysis of regional inequality induced by exports

After clarifying the characteristics of the regional inequality induced

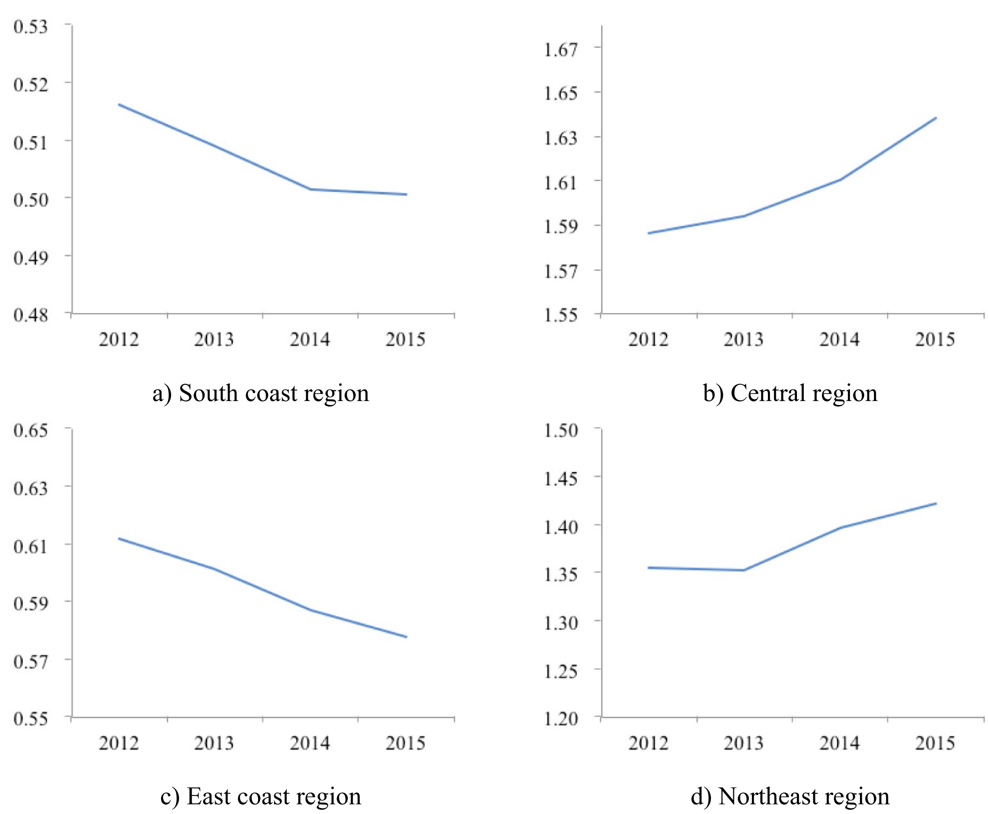


Fig. 3. The changes in *ag* index of four regions over the period 2012–2015.

by exports, the next question that policymakers are concerned with is which sector should be the target of trade-related environmental regulations. To be simple, electronic products are China's main ordinary exported products, which accounted for 58.17% of China's processing exports in 2012. Meanwhile, textile and clothing apparel products (textiles, hereafter) account for 15.55% of China's ordinary exports. Since the east coastal and south coastal regions correspond to the largest scale of ordinary and processing exports in China, this study primarily focuses on the value added and APE embodied in ordinary exports of textile in the east coastal region and processing exports of electronic products in the south coast region.

The results show that the value added generated by ordinary exports of Textiles on the east coast reached 484.58 billion RMB, 76.63% of which is actually obtained by the east coastal region itself. However, the east coast only emitted 65.43% (or 258.42 thousand tons) of gross APE (394,96 thousand tons) for the production of its ordinary exports of textiles. This result highlights that the east coast earns disproportionately more benefits from its ordinary exports. The mismatch of trade-related value added and APE is more obvious for processing exports in the south coastal region. The south coastal region's emissions embodied in its processing exports of electronic products account for only 41.59% (34.69 thousand tons) of the gross exported APE embodied in the south coastal region's processing exports. However, the south coastal region earns 90.52% (279.91 billion RMB) of the value added embodied in its processing exports. To analyze the spatial mismatch of economic benefits and environmental impacts of ordinary and processing exports, we provide a more detailed explanation of the other regions' value added and APE embodied in the east coastal region's ordinary exports of textiles and the south coastal region's processing exports of electronic products in Figs. 4 and 5.

Central regions benefit most from the ordinary exports of textiles in the east coastal region and processing exports of electronic products in the south coastal region. The central region also generates the largest volume of APE to support the ordinary exports of textiles in the east coastal region and the processing exports of electronic products in the south coastal region. From the sectoral perspective, the electricity generation sector corresponds to the largest scale of emissions induced by the ordinary exports of textiles in the east coastal region and processing exports of electronic products in the south coastal region. In addition, the ordinary and processing exports of the corresponding products also promote the emissions of the trade and transport sector and the metal product sector obviously. Ordinary exports of textiles in the east coastal region contribute most to the value added of the agricultural sector in the central region (11.08 billion RMB) and the value added of the mining sector in the northwest region (10.65 billion RMB). Processing exports of electronic products in the south coastal region contribute most to the value added of the electronic products sector in the east coastal region (1.52 billion RMB) and the central region (1.35 billion RMB).

The *ag* index of the ordinary exports of textiles in the east coastal region is represented by the ratio of the share of APE emitted by the other seven regions to the share of value added obtained by the other seven regions. The *ag* indexes of the ordinary exports of textiles in the east coastal region and processing exports of electronic products in the south coastal region are 1.48 and 5.99, respectively. This finding is consistent with the above conclusion that processing exports contribute to a more serious regional unequal distribution of trade-related APE and value added. To clarify the role that a sector plays in the regional unbalanced distribution of trade-related economic gains and environmental impacts, we recalculate the *ag* index values assuming that this sector's value added and APE induced by exports are all obtained or emitted by the exporting region. If the *ag* index values decrease, this sector plays a dominant role in the regional mismatch of trade-related APE and value added. If the *ag* indexes increase, this sector plays an important role in offsetting the regional mismatch of trade-related APE and value added. The calculation results are presented in Figs. 6 and 7.

The electricity generation sector (C14) plays a dominant role in the regional unbalanced distribution of trade-related value added and APE. Ignoring the other seven regions' trade-related value added and APE in the electricity generation sector, the *ag* index would decree from 1.48 to 0.92. For the south coast region's processing exports of electronic products, if we do not consider all trade-related value added and APE in the electricity-generation sector to the south coastal region, the other seven regions' *ag* index would decrease from 5.99 to 3.73. The trade-related value added an APE in the metal products sector (C9) and non-metallic mineral product sector (C8) also have a positive contribution to the *ag* index. However, it is obvious that the electricity-generation sector plays a dominant role in solving the problem of regional unbalanced distribution of trade-related value added and APE. China applied the administered electricity price. The low electricity price could not reflect the scarcity of energy resources and the costs for abating emissions generated during electricity production. Most power plants in the inland regions are state-owned, with corporate headquarters located in the coastal regions, such as Beijing and Shanghai. The tax revenue generated by the power plants in the inland regions is pumped away by the coastal regions. The inland regions obtain a smaller share of trade-related value added relative to the share of APE they emit. Therefore, the electricity-generation sector contributes most to the regional unequal distribution of trade-related APE and value added. The coastal region should transfer more economic revenues to the electricity

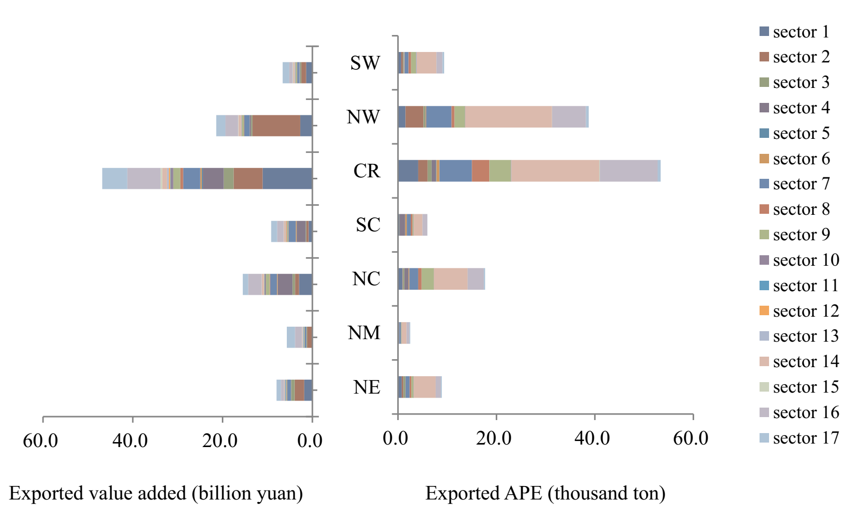


Fig. 4. Value added and APE embodied in east coast's ordinary exports of textiles.

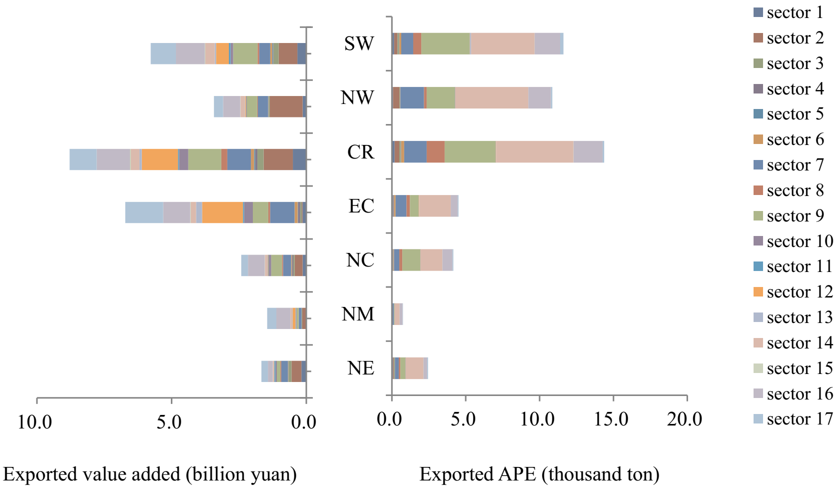


Fig. 5. Value added and APE embodied in south coast's processing exports of electronic products.

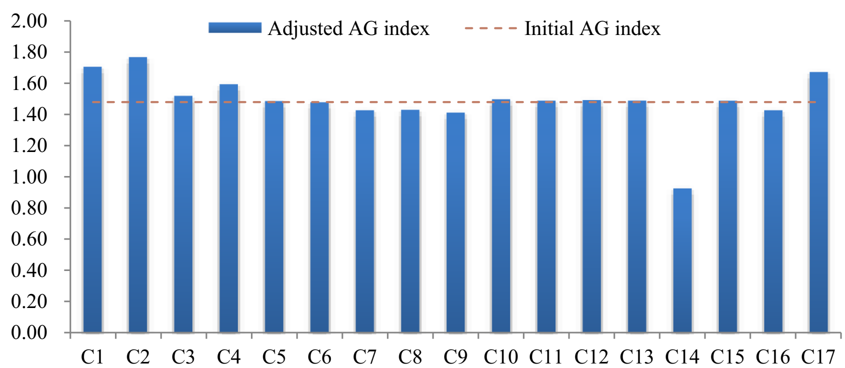


Fig. 6. Initial and adjusted AG index of east coast's ordinary exports of textiles.

generation region. In addition, the coastal regions should supply technology and capital to support pollution abatement in the coastal regions.

4. Conclusions

China has been the world's largest exporting country and faces serious regional inequality in terms of income and pollution. We analyze the effect of trade on regional inequality by measuring the regional unbalanced distribution of trade-related APE and value added among different regions. This study contributes to the related literature by making a detailed distinction between ordinary and processing exports, with the latter accounting for as much as 39.54% of the gross exports in 2012. Several interesting conclusions are drawn below.

First, although processing exports are cleaner than ordinary exports, the value added and pollution embodied in processing exports are more unequally distributed among different regions. In 2012, processing exports accounted for 39.54% of China's gross exports. The value added and APE embodied in China's processing exports accounted for only 23.52% and 17.31% of China's gross trade-related value added and APE, respectively. The inland regions obtained relatively fewer trade-related economic gains and emitted greater trade-related APE. For instance, the northwest region received only 5.43% of China's exported value added.

Second, failing to distinguish between ordinary and processing exports would overestimate the trade-related value added and APE and underestimate the regional unbalanced distribution of these two terms. Trade-related APE (value added) was overestimated by 15.58% (10.69%) in 2012. The pollution intensity of China's exports is overestimated by 4.41%. By region, the pollution intensity in the coastal region is more significantly overestimated than that in the inland regions. This would trivialize the regional inequality in trade-related economic gains and environmental impacts. Over time, there is an obvious decreasing trend in regional inequality induced by processing exports.

Third, this study also implements a detailed sectoral analysis to identify the key sectors of solving the regional mismatch of trade-related value added and APE. It is found that the electricity sector plays a dominant role. The electricity generation sector emits the largest share of pollutants to support China's exports. If we recalculate the *ag* index without considering other regions' trade-related value added and pollutions in the electricity sector, we can see that the environmental and economic justice index decrease significantly. For the east coastal region's ordinary exports of textiles, the environmental and economic justice index decreases from 1.48 to 0.92. For the south coastal region's processing exports of electronic products, the environmental and economic justice index decreases from 5.99 to 3.73.

The findings of this study have important policy implications. Exports not only directly contribute to regional income inequality,[3] but also lead to regional inequality through an unequal distribution of trade-related pollution, which has substantial adverse effects on health (Yang et al., 2013) and in turn results in large economic losses (WHO Regional Office for Europe OECD, 2015). Policymakers should pay

[3] Other possible factors also include resource endowments (Fleisher et al., 2010), foreign direct investment (Fleisher et al., 2010; Zhang and Zhang, 2003), decentralization (Kanbur and Zhang, 2005), and so on.

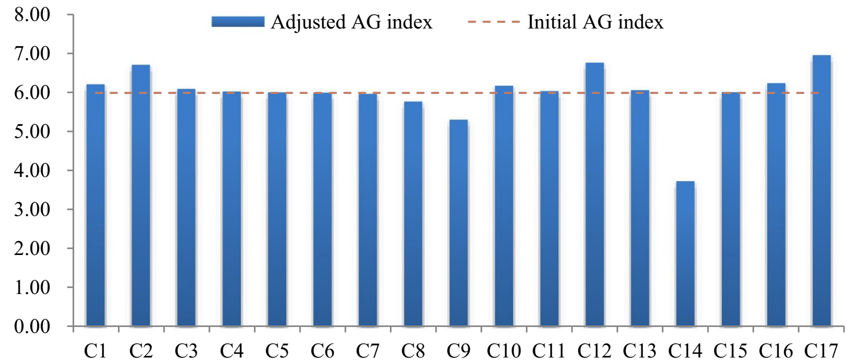


Fig. 7. Initial and adjusted AG index of the south coast's processing exports of electronic products.

attention to the equal distribution of trade-related economic benefits among different regions. From a regional perspective, the Chinese government should establish a pollution compensation mechanism between coastal and inland regions. Then, coastal regions can transfer a greater share of trade-related value added to support the sustainable development of inland regions, which bear a large share of pollution costs to support export production in coastal regions. For instance, the government may raise the electricity price level to cover the environmental costs of power plants that are mainly located in inland provinces. From a national perspective, the Chinese government should further restrict exports of pollution-intensive products and encourage the inland regions to actively and directly participate in global production networks to obtain more economic benefits.

Acknowledgements

The authors gratefully acknowledge the financial support from National Key R&D Program of China (2018YFC0213600), National Natural Science Foundation of China (71603179, 71603097, 71704195, and 71602142), Young Talents program of Central University of Finance and Economics (QYP1807). We also would like to thank the anonymous referees and the editors.

Appendix A. Classification of China's 17 sectors

	Abbreviation	Sectors
Sector 1	C1	Agriculture
Sector 2	C2	Mining
Sector 3	C3	Food products
Sector 4	C4	Textile and clothing apparel
Sector 5	C5	Wooden products
Sector 6	C6	Paper and printing
Sector 7	C7	Chemical products
Sector 8	C8	Non-metallic mineral products
Sector 9	C9	Metal products
Sector 10	C10	Machinery
Sector 11	C11	Transport equipment
Sector 12	C12	Electronic products
Sector 13	C13	Other manufacturing products
Sector 14	C14	Electricity, gas and water supply
Sector 15	C15	Construction
Sector 16	C16	Trade and transport
Sector 17	C17	Other services

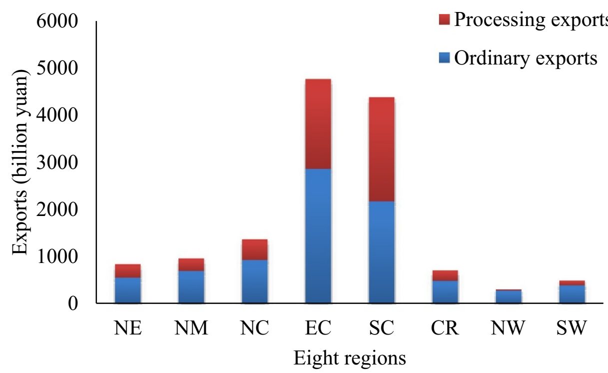
Appendix B. Classification of China's eight regions

	Abbreviation	Province included
Northeast region	NE	Heilongjiang, Jilin, Liaoning
Northern municipalities	NM	Beijing, Tianjin
North coastal region	NC	Hebei, Shandong
East coastal region	EC	Shanghai, Jiangsu, Zhejiang
South coastal region	SC	Guangdong, Fujian, Hainan
Central region	CR	Shanxi, Henan, Hubei, Hunan, Anhui, Jiangxi
Northwest region	NW	Inner Mongolia, Shaanxi, Ningxia, Gansu, Xinjiang
Southwest region	SW	Sichuan, Chongqing, Yunnan, Guizhou, Guangxi, Qinghai, Tibet

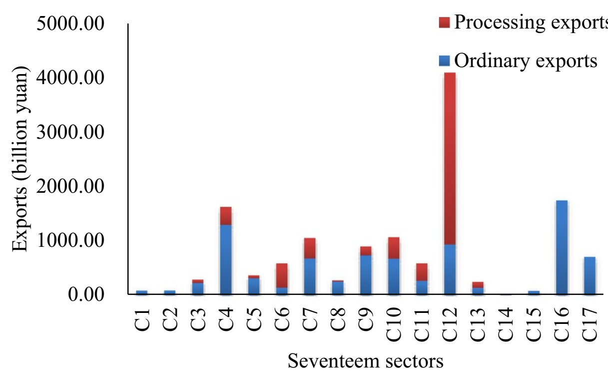
Note: In Mainland China's 31 provincial administrative areas, which are listed above, the Coastal areas include Liaoning, Tianjin, Hebei, Shandong, Shanghai, Jiangsu, Zhejiang, Guangdong, Fujian, Hainan and Guangxi.

Appendix C. China's ordinary and processing exports in 2012

In 2012, China's gross exports reached as high as 13,774 billion yuan. Ordinary and processing exports reached 8328 and 5446 billion yuan, accounting for 60.46% and 39.54% of the gross exports, respectively. The share of processing exports is so high that trade heterogeneity has a significant impact on the evaluation of the economic and environmental effects of international trade (Dietzenbacher et al., 2012; Yang et al., 2015). We provide a more detailed explanation of trade heterogeneity from regional and sectoral perspectives. The results are presented in Fig. C.1.



a) Ordinary and processing exports in eight regions



b) Ordinary and processing exports of seventeen sectors

Fig. C.1. China's ordinary and processing exports in 2012.

Fig. C.1.a presents eight regions' exports in 2012, with a distinction between ordinary and processing exports. China's exports are mainly concentrated in the coastal regions. The east coast corresponds to the largest volume of exports (i.e., 4764 billion yuan), followed by south coast (i.e., 4379 billion yuan). The exports of these two regions account for 66.37% of China's gross exports. Processing exports show much more obvious characteristics of regional agglomeration. Processing exports account for 50.53% and 40.04% of the gross exports in the south and east coastal regions. The processing exports of these two regions account for as high as 75.65% of China's gross processing exports. The volume of exports in inland regions is relatively smaller. The northwest region corresponds to the lowest volume of exports (i.e., 297 billion yuan). The processing exports account for only 7.47% of the northwest region's gross exports.

Fig. C.1.b presents the volume of exported products and services corresponding to seventeen sectors, by two different trade modes. Electronic products (C12) correspond to the largest volume (i.e., 4101.27 billion yuan) of exports in 2012, followed by trade and transport (i.e., 1746.78 billion yuan; C16) and textile and clothing apparel (i.e., 1624.75 billion yuan; C4). The large volume difference among exports of these three sectors is primarily due to the processing exports. Processing exports of electronic products account for as much as 77.23% of exported electronic products. By only looking at ordinary exports, Sector C16 ranked first (accounting for 21.97%) in China's ordinary exports, followed by Sector C4 (accounting for 15.55%). It is obvious that electronic products dominate the processing exports. Processing exports of electronic products accounts for 58.17% of China's gross processing exports. This result is consistent with the fact that most of Apple's products are labeled ‘Assembled in China’.

Appendix D. The structure of traditional interregional input-output table

Table D.1
The structure of traditional interregional input-output table.

	Intermediate input			Final use				Gross output or imports
	Region 1	…	Region n	Region 1	…	Region n	Exports	
Region 1	Z_{11}	…	Z_{1n}	y_{11}	…	y_{1n}	e_1	x_1
…	…	…	…	…	…	…	…	…
Region n	Z_{n1}	…	Z_{nn}	y_{n1}	…	y_{nn}	e_n	x_n
Imports	m_1	…	m_n	my_1	…	my_n	0	m
Value added	v_1	…	v_n					
Gross output	$(x_1)'$	…	$(x_n)'$					
Pollutions	f_1	…	f_n					

Appendix E. Each region's value added induced by regional exports (billion yuan)

	NE	NM	NC	EC	SC	CR	NW	SW
a) Processing exports								
Northeast	99.76	2.21	2.79	16.12	6.87	0.71	0.10	0.00
Northern municipalities	6.27	61.16	5.37	12.39	4.47	1.30	0.12	0.00
North coast	5.37	6.51	175.27	26.53	8.98	2.65	0.18	0.00
East coast	7.29	3.49	2.82	681.59	17.71	4.35	0.34	0.00
South coast	4.73	1.87	1.12	18.01	604.53	1.76	0.14	0.00
Central regions	6.64	4.15	7.24	90.17	28.24	72.94	0.36	0.00
Northwest	4.40	3.05	5.17	39.76	12.32	1.94	6.37	0.00
Southwest	2.48	1.02	1.41	16.20	20.84	1.04	0.19	15.15
b) Normal exports								
Northeast	354.37	14.34	11.68	48.26	29.54	7.38	6.79	4.18
Northern municipalities	15.01	372.87	21.53	34.28	15.94	9.40	6.56	2.42
North coast	25.91	34.74	712.18	74.91	31.92	22.74	14.57	6.36
East coast	16.27	12.50	10.19	1713.74	54.31	25.81	11.42	9.41
South coast	7.28	5.81	3.48	46.57	1487.14	11.07	5.14	14.98
Central regions	20.02	20.90	25.65	246.03	96.00	336.59	17.34	14.87
Northwest	14.83	15.94	18.20	117.77	48.16	18.00	177.14	10.25
Southwest	6.51	4.86	5.29	43.69	72.84	9.22	8.99	283.14

Appendix F. Each region's APE induced by regional exports (thousand ton)

	NE	NM	NC	EC	SC	CR	NW	SW
a) Processing exports								
northeast	95.99	3.52	4.50	23.59	9.33	1.06	0.13	0.00
northern municipalities	2.55	14.83	5.17	5.76	2.51	0.62	0.06	0.00
north coast	8.01	9.22	180.22	48.35	14.20	4.02	0.30	0.00
east coast	4.47	2.19	1.76	314.23	12.77	2.88	0.22	0.00
south coast	2.67	1.17	0.87	13.63	143.64	1.21	0.09	0.00
central region	10.89	8.78	16.66	159.73	46.24	61.32	0.62	0.00
northwest	14.38	11.70	15.67	107.40	37.16	5.87	27.11	0.00
southwest	4.17	2.05	3.15	32.86	41.07	2.16	0.31	19.47
b) Normal exports								
northeast	508.09	22.91	17.22	65.84	38.47	10.71	9.13	5.99
northern municipalities	9.04	145.24	18.10	15.79	9.22	5.40	3.86	1.59
north coast	32.85	52.35	894.77	126.84	48.64	36.20	21.03	9.29
east coast	10.28	7.93	6.05	1130.47	39.53	18.36	7.99	6.66
south coast	5.26	4.75	2.80	35.02	902.60	9.04	4.01	10.36
central region	33.07	49.81	57.47	401.75	152.35	505.49	29.86	24.20
northwest	47.88	65.50	54.88	288.07	137.00	53.75	462.29	33.82
southwest	11.50	10.27	11.10	83.41	133.88	20.02	18.67	477.83

References

Chen, X., Cheng, L.K., Fung, K.C., Lau, L.J., Sung, Y., Zhu, K., Yang, C., Pei, J., Duan, Y., 2012. China economic review domestic value added and employment generated by Chinese exports: a quantitative estimation. China Econ. Rev. 23, 850–864.

Chen, Q., Zhu, K., Liu, P., Chen, X., Tian, K., Yang, L., Yang, C., 2018. Distinguishing China's processing trade in the world input-output table and quantifying its effects. Econ. Syst. Res. 0, 1–21.

Dietzenbacher, E., Pei, J., Yang, C., 2012. Trade, production fragmentation, and China's carbon dioxide emissions. J. Environ. Econ. Manag. 64, 88–101.

Duan, Y., Los, B., Yang, C., Dietzenbacher, E., 2014. A new interregional input output for China: construction and application. In: The 22nd International Input-Output Conference, (Portugal).

Feng, K., Davis, S.J., Sun, L., Li, X., Guan, D., Liu, W., Liu, Z., Hubacek, K., 2013. Outsourcing CO_2 within China. Proc. Natl. Acad. Sci. U. S. A. 110, 11654–11659.

Fleisher, B., Li, H., Zhao, M.Q., 2010. Human capital, economic growth, and regional inequality in China. J. Dev. Econ. 92, 215–231.

Fukuda, K., 2018. Trade integration and regional income disparities in a growth model with the service sector and footloose capital. Appl. Econ. Lett. 0, 1–4.

Gill, N., 2006. How Does Trade Affect Regional Disparities? 34. pp. 1201–1222.

Jiang, X., Guan, D., Zhang, J., Zhu, K., Green, C., 2015. Firm ownership, China's export related emissions, and the responsibility issue. Energy Econ. 51, 466–474.

Jiang, X., Chen, Q., Guan, D., Zhu, K., Yang, C., 2016. Revisiting the global net carbon dioxide emission transfers by international trade: the impact of trade heterogeneity of China. J. Ind. Ecol. 20, 506–514.

Jiang, X., Duan, Y., Green, C., 2017. Resources, conservation and recycling regional disparity in energy intensity of China and the role of industrial and export structure. Resour. Conserv. Recycl. 120, 209–218.

Johnson, R.C., Noguera, G., 2012. Accounting for intermediates: production sharing and trade in value added. J. Int. Econ. 86, 224–236.

Kanbur, R., Zhang, X., 2005. Fifty years of regional inequality in China: a journey through central planning, reform, and openness. Rev. Dev. Econ. 9, 87–106.

Koopman, R., Wang, Z., Wei, S., 2012. Estimating domestic content in exports when processing trade is pervasive☆. J. Dev. Econ. 99, 178–189.

Li, Y., Meng, J., Liu, J., Xu, Y., Guan, D., Tao, W., Huang, Y., Tao, S., 2016. Interprovincial reliance for improving air quality in China: a case study on black carbon aerosol. Environ. Sci. Technol. 50, 4118–4126.

Meschi, E., Vivarelli, M., 2009. Trade and income inequality in developing countries. World Dev. 37, 287–302.

Mi, Z., Meng, J., Guan, D., Shan, Y., Song, M., Wei, Y.-M., Liu, Z., Hubacek, K., 2017. Chinese CO_2 emission flows have reversed since the global financial crisis. Nat. Commun. 8, 1712.

Ministry of Environmental Protection (MEP), 2013. Annual Statistic Report on Environment in China 2012. (in Chinese).

(MEP), M. of E.P, 2008. Annual Statistic Report on Environment in China 2007. (in Chinese).

Organisation for Economic Co-operation and Development (OECD), 2015. OECD Inter-Country Input–Output (ICIO) Tables, Edition 2015. Organisation for Economic Co-operation and Development, Paris.

Pei, J., Oosterhaven, J., Dietzenbacher, E., 2012. How much do exports contribute to China's income growth? Econ. Syst. Res. 24, 275–297.

Pei, J., Oosterhaven, J., Dietzenbacher, E., 2015. Foreign exports, net interregional spillovers and Chinese regional supply chains foreign exports, net interregional spillovers and Chinese regional supply chains*. Pap. Reg. Sci.

Su, B., Ang, B.W., Low, M., 2013. Input-output analysis of CO_2 emissions embodied in trade and the driving forces: processing and normal exports. Ecol. Econ. 88, 119–125.

Wang, Y., Bi, F., Zhang, Z., Zuo, J., Zillante, G., Du, H., Liu, H., Li, J., 2018. Spatial production fragmentation and $PM_{2.5}$ related emissions transfer through three different trade patterns within China. J. Clean. Prod. 195.

WHO Regional Office for Europe OECD, 2015. Economic Cost of the Health Impact of Air Pollution in Europe: Clean Air, Health and Wealth. WHO Reg. Off. Eur, Copenhagen, pp. 1–54.

Xia, Y., Fan, Y., Yang, C., 2015. Assessing the impact of foreign content in China's exports on the carbon outsourcing hypothesis. Appl. Energy 150, 296–307.

Xie, Y., Zhou, X., 2014. Income inequality in today's China. Proc. Natl. Acad. Sci. 111, 6928–6933.

Yang, J., Wang, J., 1998. Reforming and Design of Pollution Levy System in China. China Environmental Science Press, Beijing.

Yang, G., Wang, Y., Zeng, Y., Gao, G.F., Liang, X., Zhou, M., Wan, X., Yu, S., Jiang, Y., Naghavi, M., Vos, T., Wang, H., Lopez, A.D., Murray, C.J.L., 2013. Rapid health transition in China, 1990–2010: findings from the global burden of disease study 2010. Lancet 381, 1987–2015.

Yang, C., Dietzenbacher, E., Pei, J., Chen, X., Zhu, K., Tang, Z., 2015. Processing trade biases the measurement of vertical specialization in China. Econ. Syst. Res. 27, 60–76.

Zhang, Z., Lin, J., 2018. From production-based to consumption-based regional carbon inventories: insight from spatial production fragmentation. Appl. Energy 211, 549–567.

Zhang, X., Zhang, K.H., 2003. How does globalisation affect regional inequality within a developing country? Evidence from China. J. Dev. Stud. 39, 47–67.

Zhang, W., Wang, F., Hubacek, K., Liu, Y., Wang, J., Feng, K., Jiang, L., Jiang, H., Zhang, B., Bi, J., 2018. Revealing environmental inequality hidden in China's inter-regional trade. Environ. Sci. Technol. 52, 3888–3898.