The Environmental Pains and Economic Gains of Outsourcing to China

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Abstract: When taking into account the dominant share of processing exports in overall exports volume, for instance 51% in 2007 (55% in 2002), it is crucial to address greenhouse gas emission issue generated in exports by processing type. Contrary to most previous studies, it is found that processing exports have lower pollution coefficient, which implies Chinese exports contribute relatively low to climate change (e.g. CO2 emissions generated by processing exports account for 2%, and non-processing exports contribute 10% of total emissions). Following these findings, different from ordinary exports, processing exports are especially coherent with "emissions avoided by imports" fashion; in turn, the pollution balance turns out to be much smaller than ordinary ones.

On the other hand, a lot of work has been done currently, qualitatively or quantitatively, on the value added or economic benefits for China generated by processing exports, and most people argue that although the volume of processing export are quite large, its economic benefits are relatively small (to give an example, the total domestic value added generated by 1 unit processing exports is about 0.287; however, the benefit gains from 1 unit non-processing exports is roughly 0.633).

Needless to say, processing trade will be a most important part in China's trade in a rather long time in the future (though probably with a gradual diminishing share), we argue that processing trade to China is an "environmentally-friendly" export type (compared with similar products in ordinary trade) since it has a much shorter domestic production chain. Meanwhile it could be viewed as climate change (less) harmless behavior, though at the cost of value added, or gains and pains game. Furthermore, it would be highlighted that one of the most important things for China is how to adjust the

products share in processing trade, in order to get a trade-off between climate change control and economic benefits.

Keywords: processing exports; climate change; value added; pains and gains

JEL Codes: C67; Q56; O47; F14

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1. Introduction

Globalization has many facets, one of them being the upsurge of trade in emissions, Copeland and Taylor (2004) gives an excellent review on trade-environment literature. It is well known that some countries that have ratified the Kyoto protocol transfer some of their polluting production activities to so-called pollution havens with regulations that are more lax. As a consequence, these countries may meet the targets whereas they are responsible for an increase in worldwide pollution. This has raised the discussion whether to focus on the producer’s responsibility (i.e. all emissions generated by the production activities of a country) or the consumer’s responsibility (i.e. all emissions that are necessary worldwide to satisfy the needs of the ‘consumers’ of a country, where ‘consumption’ includes private and government consumption and investments), see e.g. Gallego and Lenzen (2005), Rodrigues *et al*. (2006), and Lenzen and Murray (2007) for recent contributions. The difference between the two responsibilities is given by the trade in emissions (Serrano and Dietzenbacher, 2008). This issue has also reached the policy debate, as witnessed by the question whether China can be held responsible for all of its emissions. Weber *et al*. (2008), for example, have estimated that roughly one third of China’s greenhouse gas (GHG) emissions were due to exports and thus ‘on behalf of foreign consumers’.

Another facet of globalization is the increase in outsourcing (and offshoring) production activities to other countries. Due to low wages, in particular developing countries have been targeted for outsourcing in order to cut the production costs. This implies a huge amount of processing trade. In the case of processing trade, a large share (or even all) of the raw and auxiliary materials, parts and components, accessories, and packaging materials are imported from abroad free of duty, and the finished products are re-exported again after they have been processed or assembled by enterprises. For example, for China we find (see Figure 1) that these processing exports have accounted for more than 50% of its annual total exports in the period 1995-2007 (although it is expected to decline slowly because outsourcing to China will become less attractive due to raising wages).

Insert Figure 1

In this paper, we focus on China's exports. Because processing exports typically involve the input of labor, e.g. for assembly, and little Chinese intermediate inputs, the Chinese part of the production chain of these goods is relatively short (when compared to the production of 'ordinary' or non-processing exports). Also relatively little GHGs will be emitted in China. As a consequence, when calculating the Chinese emissions involved in China's exports, it is important to make a distinction between processing exports and non-processing exports. Our first major finding is that Chinese emissions necessary for the country's exports are overestimated by more than 60%, if the distinction between processing and non-processing exports is *not* taken into account.

For our analysis we use an input-output (IO) framework. In particular for ascribing (i.e. measuring) certain effects (e.g. emissions) to actions that have taken place (e.g. exports or private consumption), the IO framework is appropriate. It includes the technical relationships involved in the production process and does not require the modeling and simulation of economic behavior (for which the CGE approach is more appropriate). Also, a major advantage is that nowadays many national IO tables are available at a detailed level and are complemented by additional data (e.g. environmental data) at the same level. See Miller and Blair (1985) for an introduction to IO analysis, overviews focusing on the use of IO to analyze environmental issues are included in Forssell (1998), Forssell and Polenske (1998), Suh and Kagawa (2005), Turner *et al*. (2007), and Wiedmann *et al*. (2007).

Recently, a special, tripartite IO table has been estimated for China. The table distinguishes between the following three categories: production for domestic purposes only; production for processing exports; and production for non-processing exports and other production of foreign owned enterprises (see Lau *et al*., 2006, 2007, for details of the table construction). Its compilation has become possible, because imported goods under the item of processing trade (i.e. processing imports) can—according to the official regulations—only be used to produce goods for processing exports, but not for other purposes (such as domestic sales). The consequence is that the customs and tax authorities had collected much of the underlying information for this tripartite IO table.

Much outsourcing takes place to low-wage countries. The implication is that the value added in the host country (such as China) will increase due to processing exports. This increase, however, is much less than in the case the same amount would have been produced for non-processing exports. This is because non-processing exports require much more domestic inputs than processing exports (which rely almost entirely on processing imports). The tripartite IO table includes also information on value added and using this table, Lau *et al*. (2006, 2007) report that the total domestic value added generated by 1000 Renminbi (Rmb) of processing exports and non-processing exports are 287 Rmb and 633 Rmb, respectively.

An old saying states "no pains, no gains". The 'gains' from outsourcing to China are that its value added (or GDP) increases, whereas the 'pains' are an increase in Chinese emissions.[1] We have argued that both the 'gains' and the 'pains' are smaller for processing exports than they are for non-processing exports. Yet, by taking their ratio (or cost-benefit ratio), it turns out that the first is much more favorable than the latter. That is, our second major finding is that processing exports have a substantially lower cost-benefit ratio than non-processing exports.

The remainder of the paper is structured as follows. Section 2 introduces the methodology and deals with data issues; Section 3 discusses the 'pains' and the 'gains', and compares their ratio for the different types of exports. Section 4 concludes and Section 5 discusses and provides some policy recommendations.

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[1] In particular the 'gains' have received ample attention in the recent literature. For example, see Feenstra *et al*. (1999), Fung and Lau (2001), Feenstra and Hanson (2004), Fung *et al*. (2006), and Ferrantino and Wang (2008) for the necessary adjustments in the bilateral trade statistics, see Rodrik (2006), Schott (2006), and Feenstra and Hong (2007) for estmating the exports' contribution to Chinese economic growth, and see Lau *et al*. (2006, 2007), Zhu *et al*. (2007), and Koopman *et al*. (2008) for focusing on the characteristics of China's processing exports and pointing out their relatively small economic benefits.

2. Methodology

Our starting point is a unique, tripartite IO table for China in 2002, the structure of which is outlined in Figure 2[2]. Three types (or classes) of production are distinguished: industries with enterprises producing only for domestic use (indicated by superscript *D*); industries with enterprises producing processing exports (*P*); and the combination of industries with enterprises producing non-processing exports and with ‘other production’ of foreign-invested enterprises. With respect to the last category, foreign-invested enterprises directly export approximately half of their production (which is included in the processing exports). The remaining half is used as domestic intermediate input or is for domestic final demand purposes. Still, this other production of foreign-invested enterprises is taken together with the production of non-processing exports and is not taken together with production for domestic use. Because the inputs for most of this other production are imported, the input structure is more similar to that of production of non-processing exports than to that of production for domestic use.

Insert Figure 2

The framework is very similar to that of an interregional IO (IRIO) table with three regions (see Miller and Blair, 1985). Each class (or region in the IRIO case) has the same industries and produces the same goods and services. Our dataset covers n = 28 industries, see Appendix A for the classification scheme. The element z_{ij}^{UR} of the $n \times n$ matrix Z^{UR} gives the domestic delivery of industry i (= 1, ..., n) in class U (= D, N) to industry j in class R (= D, P, N).[3] The element f_i^U of the vector $\mathbf{f}^U$ gives the final demands

[2] See Lau *et al*. (2006, 2007), Yang and Pei (2007) or Yang *et al*. (2009) for a detailed discussion and applications.
[3] Matrices are indicated by boldfaced capital letters (e.g. **Z**), vectors are columns by definition and are indicated by boldfaced lowercase letters (e.g. **x**), and scalars (including elements of matrices or vectors) are indicated by italicized lowercase letters (e.g. *c* or *α*). A prime indicates transposition (e.g. $\mathbf{x}'$) and a hat (or circumflex) indicates a diagonal matrix (e.g. $\hat{\mathbf{x}}$) with the elements of a vector (i.e. **x**) on its main diagonal and all other entries equal to zero.

for good i produced in class U (= D, N). The final demands comprise rural household consumption, urban household consumption, government consumption, gross fixed capital formation (i.e. investments), and changes in stocks and inventories. The element $\mathrm{e}_{\mathrm{i}}^{\mathrm{W}}$ of the vector $\mathbf{e}^{\mathbf{W}}$ gives the exports of good i produced in class W (= P, N). The element x_i^R of the vector $\mathbf{x}^R$ gives the domestic gross output of industry i in class R (= D, P, N). The element v_i^R of the (row) vector $(\mathbf{v}^R)'$ gives the value added in industry i produced in class R (= D, P, N), which consists of wages and salaries, capital depreciation, net taxes on production and the operating surplus. The imports consist of two types, imported inputs of good i by industry j in class R (= D, P, N) are given by element m_{ij}^R of the matrix $\mathbf{M}^R$, and imports of good i that go directly to the final users are given by the element f_i^M of the vector $\mathbf{f}^M$. Aggregation over the classes gives the 'ordinary' national IO table (in the same way as aggregation over regions does for an IRIO table), the structure of which is outlined in Figure 3.

Insert Figure 3

The matrices of input coefficients are obtained as follows. For the 'ordinary' IO table we have $\mathbf{A} = \mathbf{Z}\hat{\mathbf{x}}^{-1}$ and its element $a_{ij} = z_{ij} / x_j$ gives the input of good i per unit of output of industry j. For the tripartite IO table we $A^{\mathrm{UR}} = Z^{\mathrm{UR}}(\hat{x}^{\mathrm{R}})^{-1}$ with U = D, N, and R = D, P, N. Its element $\mathrm{a}_{\mathrm{ij}}^{\mathrm{UR}} = \mathrm{z}_{\mathrm{ij}}^{\mathrm{UR}} / \mathrm{x}_{\mathrm{j}}^{\mathrm{R}}$ gives the input of good i from class U per unit of output of industry j in class R. Let us write $\overline{\mathbf{A}}$ for the 3n×3n input matrix in the tripartite case, with

$$\overline{\mathbf{A}} = \begin{bmatrix} \mathbf{A}^{DD} & \mathbf{A}^{DP} & \mathbf{A}^{DN} \\ 0 & 0 & 0 \\ \mathbf{A}^{ND} & \mathbf{A}^{NP} & \mathbf{A}^{NN} \end{bmatrix} \quad (1)$$

For the 'ordinary' IO table in Figure 3, we now have that $\mathbf{x} = \mathbf{A}\mathbf{x} + (\mathbf{f} + \mathbf{e})$, or

$\mathbf{x} = (\mathbf{I} - \mathbf{A})^{-1}(\mathbf{f} + \mathbf{e}) = \mathbf{L}(\mathbf{f} + \mathbf{e})$, where $\mathbf{L} = (\mathbf{I} - \mathbf{A})^{-1}$ is the Leontief inverse. The outputs that are necessary for satisfying the domestic final demands, respectively the exports, are given by $\mathbf{Lf}$ and $\mathbf{Le}$, respectively. Let the element r_i of the (row) vector $\mathbf{r}'$ represent the emissions of a certain pollutant by industry *i*. The direct emission coefficients are obtained as $\boldsymbol{\mu}' = \mathbf{r}'\hat{\mathbf{x}}^{-1}$ and its element $\mu_i = r_i / x_i$ gives the emissions by industry *i* per unit of its gross output. The total amount of emissions due to, for example, the exports are then given by the scalar $\boldsymbol{\mu}'\mathbf{Le}$. The *i*th element of the row vector $\boldsymbol{\mu}'\mathbf{L}\hat{\mathbf{e}}$ gives the total emissions necessary for the exports of product *i*, and the *i*th element of the column vector $\hat{\boldsymbol{\mu}}\mathbf{Le}$ gives the emissions by industry *i* necessary for all exports. In our application, we will use

$$\mathbf{g}^{(\mathbf{f})} = \hat{\boldsymbol{\mu}}\mathbf{Lf} \tag{2a}$$

$$\mathbf{g}^{(\mathbf{e})} = \hat{\boldsymbol{\mu}}\mathbf{Le} \tag{2b}$$

In the same fashion, we find for the tripartite IO table in Figure 2 that the Leontief inverse is given by

$$\overline{\mathbf{L}} = (\mathbf{I} - \overline{\mathbf{A}})^{-1} = \begin{bmatrix} \mathbf{L}^{DD} & \mathbf{L}^{DP} & \mathbf{L}^{DN} \\ 0 & \mathbf{I} & 0 \\ \mathbf{L}^{ND} & \mathbf{L}^{NP} & \mathbf{L}^{NN} \end{bmatrix} \tag{3}$$

The direct emission coefficients are given by $(\boldsymbol{\mu}^D)' = (\mathbf{r}^D)'(\hat{\mathbf{x}}^D)^{-1}$ for type *D* producers (and similar expressions for type *P* and *N* producers). The emissions that are necessary for each of the four categories of final use in Figure 2, are given by

$$\mathbf{g}^{(\mathbf{f}^D)} = (\hat{\boldsymbol{\mu}}^D\mathbf{L}^{DD} + \hat{\boldsymbol{\mu}}^N\mathbf{L}^{ND})\mathbf{f}^D \tag{4a}$$

$$\mathbf{g}^{(\mathbf{f}^N)} = (\hat{\boldsymbol{\mu}}^D\mathbf{L}^{DN} + \hat{\boldsymbol{\mu}}^N\mathbf{L}^{NN})\mathbf{f}^N \tag{4b}$$

$$\mathbf{g}^{(\mathbf{e}^P)} = (\hat{\boldsymbol{\mu}}^D\mathbf{L}^{DP} + \hat{\boldsymbol{\mu}}^P + \hat{\boldsymbol{\mu}}^N\mathbf{L}^{NP})\mathbf{e}^P \tag{4c}$$

$$\mathbf{g}^{(\mathbf{e}^N)} = (\hat{\boldsymbol{\mu}}^D \mathbf{L}^{DN} + \hat{\boldsymbol{\mu}}^N \mathbf{L}^{NN})\mathbf{e}^N \tag{4d}$$

where, for example, the *i*th element of the column vector in (4a) indicates the emissions by all industries *i* (i.e. in class *D*, *P* and *N*) that are necessary for satisfying the domestic final demands for goods produced in class *D*.

For calculating the emissions in China that correspond to the different categories (such processing exports and non-processing exports), we have used the data on actual emissions as reported in Peters *et al*. (2006). These emissions data, however, do not distinguish between the three classes of production. Therefore we have run two sets of calculations. The first set assumes that the emission coefficient for industry *i* is the same in each class. That is, we have used $\boldsymbol{\mu}^D = \boldsymbol{\mu}^P = \boldsymbol{\mu}^N = \boldsymbol{\mu}$, where $\boldsymbol{\mu}$ is the vector of emission coefficients based on Peters *et al*. (2006).

For the second set of calculations, we have estimated separate coefficients for each of the three classes. The idea is that product *i* has a comparable output value no matter whether it is produced in class *D* or *P*. However, in class *P* the production of this good relies heavily on imported inputs (i.e. processing imports) and some labor for assembly for example. Only a very small part of its production chain is situated in China, in contrast to production in class *D* where a large part of the production chain is in China. Therefore it seems plausible that also the emissions of industries in class *P* are only a fraction of those of industries in class *D*, as suggested in Converse (1971). The industries in class *N* are expected to take an intermediate position. The estimation of the emission coefficients is based on the extent to which an industry relies on domestic intermediate inputs. In the overall case (corresponding to Figure 3) we have that the domestic intermediate inputs of industry *i* are given by the *i*th element of the row vector $\boldsymbol{\rho}' = \mathbf{s}'\mathbf{A}$, where $\mathbf{s}$ indicates the summation vector consisting of ones. The domestic intermediate inputs in each of the three classes is given by $(\boldsymbol{\rho}^D)' = \mathbf{s}'(\mathbf{A}^{DD} + \mathbf{A}^{ND})$, $(\boldsymbol{\rho}^P)' = \mathbf{s}'(\mathbf{A}^{DP} + \mathbf{A}^{NP})$ and $(\boldsymbol{\rho}^N)' = \mathbf{s}'(\mathbf{A}^{DN} + \mathbf{A}^{NN})$. The estimated emission coefficients are then obtained as

$$\mu_i^D = \frac{\rho_i^D}{\rho_i}\mu_i\,,\ \mu_i^P = \frac{\rho_i^P}{\rho_i}\mu_i\,,\ \text{and}\ \mu_i^N = \frac{\rho_i^N}{\rho_i}\mu_i \tag{5}$$

Note that these class-specific emission coefficients still yield the correct total emissions in each industry. That is,

$$\mu_i^D x_i^D + \mu_i^P x_i^P + \mu_i^N x_i^N = \mu_i x_i = r_i \tag{6}$$

the proof of which is given in Appendix B.

Finally, a similar set of calculations has been carried out for the value added in each industry. That is, define the value added coefficients as $\boldsymbol{\upsilon}' = \mathbf{v}'\hat{\mathbf{x}}^{-1}$, with $\mathbf{v}$ the value added vector from Figure 3. Replacing the vector $\boldsymbol{\mu}$ by $\boldsymbol{\upsilon}$ in equations (2) then gives the value added in each industry that is generated by the domestic final demands and by the exports, respectively. In the case of Figure 2, we have $(\boldsymbol{\upsilon}^R)' = (\mathbf{v}^R)'(\hat{\mathbf{x}}^R)^{-1}$ with $R = D, P, N$, and replacing $\boldsymbol{\mu}^R$ by $\boldsymbol{\upsilon}^R$ in equations (4) provides the vectors with values added for each of the four categories of final use.

3. The Results for China in 2002

3.1. The Pains and Gains

Table 1 presents the results at the aggregate (national) level, i.e. the emissions in each industry have been summed over the industries. It gives the emissions (of CO_2, SO_2, and NO_x) and the values added that can be ascribed to the domestic final demands (such as private consumption, private investments, and government expenditures) and to the exports. Using the tripartite IO table for China in 2002, we have four final demand categories: domestic final demands for goods and services produced by enterprises that produce for domestic use only ($\mathbf{f}^D$) and by enterprise that produce non-processing exports ($\mathbf{f}^N$); processing exports ($\mathbf{e}^P$); and non-processing exports ($\mathbf{e}^N$). The formulae for calculating the emissions at the industry level are given by equations (4a)–(4d), respectively. As we have mentioned, the tripartite IO table for China is a unique table that takes the special characteristics of processing exports into full account. Usually, calculations have to be done using the ‘ordinary’ national IO table, which sketches an average input structure. In order to highlight the consequences of this, we have also calculated the emissions and values added generated in satisfying domestic final demands (**f**) and the exports (**e**), using the ‘ordinary’ IO table. The corresponding equations are (2a) and (2b). For the emissions in the tripartite framework, we have done two sets of calculations. The results in the rows ‘separate coeffs’ are obtained from using class-specific emission coefficients that have been estimated according to equation (5), the results in the rows ‘identical coeffs’ are obtained from using the assumption that emission coefficients are the same across classes (i.e. $\boldsymbol{\mu}^D = \boldsymbol{\mu}^P = \boldsymbol{\mu}^N = \boldsymbol{\mu}$).

Insert Table 1

Peters *et al.* (2006) report that the overall CO_2 emissions generated by industries amounted to 3406.3 Mt in 2002, while 100.4 Mt was generated by urban residents, and 80.6 by rural residents (i.e. 95%, 3% and 2% of the total emissions, respectively). The focus in this paper is on the 95% of the emissions that are generated by industry production.

Several observations follow from the results in Table 1. First, the role of exports in generating Chinese emissions. Whereas Weber *et al*. (2008) report that exports are responsible for about 33% of the production-related CO_2 emissions in 2005 (the contribution is 21% in 2002), our results—in the rows ‘separate coeffs’, i.e. using class-specific direct emission coefficients—indicate that this is only 12.6%. This implies that an overwhelming 87.4% is due to domestic final demands (for SO_2 and NO_x emissions, domestic final demands are responsible for 88.1% and 86.0%, respectively). Second, the processing exports are responsible for only 16.6% of the export-related CO_2 emissions, whereas they are no less than 55.3% (179.9 billion US$) of the total exports in 2002. For SO_2 and NO_x emissions, the share of processing exports in export-related emissions is 15.4% and 17.2%. Third, the value added that is generated by processing exports amounts to 23.1% of all the export-related value added. When compared to the non-processing exports, this implies that processing exports generate less value added (i.e. gains) on the one hand, but much less emissions (i.e. pains) on the other hand. We will come back to this issue later.

Fourth, if the tripartite IO table would not have been available—which is the case for almost all other countries in the world—we would have been forced to use the 'ordinary' national IO table. In that case, the export-related CO_2 emissions would have been reported as 20.3% of all production-related CO_2 emissions. This is an overestimation by no less than 61% (for SO_2 and NO_x emissions, the overestimation amounts to 73% and 48%, respectively). The reason is that the 'ordinary' IO table is obtained by aggregating the tripartite table, using gross outputs as weights. Because the gross outputs of the classes P and N are relatively small, the average production (or input) structure and the direct emission coefficients—which in that case applies also to processing exports (in P) and non-processing exports (in N)—are very similar to those for domestic use only (in D).

Fifth, when we compare the results in the rows 'separate coeffs' with those in the rows 'identical coeffs' we see that much of what has been said for processing exports remains valid, but to a lesser extent. That is, the difference between processing and non-processing exports are less because the direct emission coefficients of producing processing exports are not higher than they are for producing non-processing exports. This case should be considered as the 'worst case scenario', in the sense that it provides the most conservative estimates for the emissions.

Table 2 gives the CO_2 emissions by each industry for each of the four final demand categories. We included only the results for the tripartite IO tables and for the case with class-specific direct emission coefficients. Note that the totals are the same as given in Table 1 in the row 'separate coeffs'. It is clear that for all four final demand categories, the bulk of CO_2 is emitted by only five industries. These are: 22 (Production and supply of electricity and heating power); 13 (Non-metal mineral products); 14 (Metals smelting and pressing); 26 (Transport and warehousing); and 12 (Chemicals). Together they emit 83.3% of the CO_2 due to domestic final demands produced in class D and the shares are 92.9% in case of domestic final demands produced in class N, 79.0%

in case of processing exports and 83.6% in case of non-processing exports. Also the rankings within this top five are almost the same, except for Transport and warehousing (26) which ranks at the second place for CO_2 emissions due to processing exports. This clearly reflects the relatively strong dependence of processing exports on the transport sector. The top ranking for industry 22 is not very surprising, given the fact that coal still dominates electricity production in China (since the mid 1970s, approximately 70% of the primary energy consumption is coal-based, as shown in Figure 4). One striking difference is that for the domestic final demands produced by enterprises in class P (i.e. producing non-processing exports) no less than 74.9% of the CO_2 emissions are generated by industry 22, whereas this share ranges between 35% and 45% for the other three final demand categories. The findings for SO_2 and NO_x emissions are to a very large extent the same as those for CO_2 emissions.[4]

Insert Table 2 and Figure 4

Table 3 is similar to Table 2 in the sense that it gives the value added (instead of the amount of CO_2 emissions) generated in each industry, for each of the four final demand categories. A striking difference between the two tables is that the top five industries in emitting CO_2 (i.e. 22, 13, 14, 26, and 12) play only a minor role in generating value added. Another difference between the two tables is that the set of top five industries differs largely between final demand categories, whereas the top five in terms of CO_2 emissions was the same for all final demand categories. The picture that is sketched by these results is the following. Irrespective of the product-mix of the final demand vectors, they all induce production in the five industries that generate the bulk of the CO_2 emissions. In contrast to this, different product-mixes lead to different patterns of gross output across industries, and thus to different patterns of value added. CO_2 emissions are largely determined by the production in a small set of industries (i.e. 22, 13, 14, 26, and 12). Value added can be generated in many ways, but stimulating the production in the strong CO_2 emitting industries is not very effective.

[4] The results are not included in the paper, but are available form the authors upon request.

Insert Table 3

3.2. The Pains versus the Gains

One of the overall findings in Table 1 was that the environmental pains (i.e. CO_2 emissions) and the economic gains (i.e. value added) of processing exports were smaller than those of non-processing exports. However, the pains were several times smaller whereas the gains were approximately two times smaller. In this section we will carry out a more detailed analysis of the pains versus gains by calculating their ratios, i.e. the cost-benefit ratios.

From equation (4a), we may derive that the ith element of the row vector $(\boldsymbol{\mu}^D)'\mathbf{L}^{DD} + (\boldsymbol{\mu}^N)'\mathbf{L}^{ND}$ gives the total amount of emissions per unit of final demand for good i produced in class D (for domestic use only). This is an environmental 'pain' or cost. In the same fashion, the ith element of the row vector $(\boldsymbol{\upsilon}^D)'\mathbf{L}^{DD} + (\boldsymbol{\upsilon}^N)'\mathbf{L}^{ND}$ gives the corresponding amount of value added, i.e. the economic 'gain' or benefit. Their ratio

$$\xi_i^D = \frac{[(\boldsymbol{\mu}^D)'\mathbf{L}^{DD} + (\boldsymbol{\mu}^N)'\mathbf{L}^{ND}]_i}{[(\boldsymbol{\upsilon}^D)'\mathbf{L}^{DD} + (\boldsymbol{\upsilon}^N)'\mathbf{L}^{ND}]_i}$$

expresses how much CO_2 is emitted per unit of value added, both corresponding to the final demand for good i produced in class D (i.e. f_i^D).

For the final demands for good i in the other classes (i.e. e_i^P in class P, and f_i^N or e_i^N in class N), we have the following cost-benefit ratios.

$$\xi_i^P = \frac{[(\boldsymbol{\mu}^D)'\mathbf{L}^{DP} + (\boldsymbol{\mu}^P)' + (\boldsymbol{\mu}^N)'\mathbf{L}^{NP}]_i}{[(\boldsymbol{\upsilon}^D)'\mathbf{L}^{DP} + (\boldsymbol{\upsilon}^P)' + (\boldsymbol{\upsilon}^N)'\mathbf{L}^{NP}]_i} \quad \text{and} \quad \xi_i^N = \frac{[(\boldsymbol{\mu}^D)'\mathbf{L}^{DN} + (\boldsymbol{\mu}^N)'\mathbf{L}^{NN}]_i}{[(\boldsymbol{\upsilon}^D)'\mathbf{L}^{DN} + (\boldsymbol{\upsilon}^N)'\mathbf{L}^{NN}]_i}$$

where $[...]_i$ indicates the ith element of the vector between brackets.

From the results in Table 1 we can calculate straightforwardly that the average for the processing exports vector $\mathbf{e}^P$ is 0.19, whereas it is 0.29 for the vector of non-processing exports $\mathbf{e}^N$. It should be noted, however, that this average uses value added shares as weights. That is, for the non-processing exports, for example,

$$0.29 = \frac{358.19}{1245.13} = \Sigma_i \xi_i^N w_i^N \quad \text{with} \quad w_i^N = \frac{[(\upsilon^D)' L^{DN} + (\upsilon^N)' L^{NN}]_i e_i^N}{\Sigma_i [(\upsilon^D)' L^{DN} + (\upsilon^N)' L^{NN}]_i e_i^N} \qquad (7)$$

where the denominator in w_i^N indicates the value added generated by final demand e_i^N as a share of the value added generated by all non-processing exports.

Instead of using value added shares as weights, we may also take the final demand components as the basis of the weights. For example for the processing exports this yields

$$\Sigma_i \xi_i^P w_i^P \quad \text{with} \quad w_i^P = \frac{e_i^P}{\Sigma_i e_i^P} \qquad (8)$$

Alternatively, the harmonic mean is based on the weighted average of the reciprocals. That is,

$$\frac{1}{\Sigma_i (1/\xi_i^P) w_i^P} \quad \text{with} \quad w_i^P = \frac{e_i^P}{\Sigma_i e_i^P} \qquad (9)$$

The results are given in Table 4. The results show that the ratio of ‘pains’ and ‘gains’ is smaller than that of non-processing export and domestic use. For some industry, the difference is quite large, for example 24 (water production and supply), 4 (metal ore mining), 15 (metal products).

4. Conclusions

The aim of this study is clear that we would like to estimate China’s processing exports role in two aspects: economic perspective (value added) and environmental aspect (GHG emissions). To this end, we have firstly prepared a unique input-output table which captures China's processing exports feature; and then three sets of emission coefficients are obtained accordingly; at last, we have estimated the emissions and value added generated by different types of exports by industry.

As one could anticipate, processing exports have small emission coefficients so does value added coefficients. In 2002, processing exports dominate the exports pattern and account for 55.3% of total volume. On the one hand, it only contributes 16.6 per cent of CO2 emissions by ALL exports (both processing and non-processing); while 23.1% of value added on the other. From industry level, those sectors pollute more usually accompany with less value added generation, for instance sector 22 (see Table 2 and Table 3). Compared with Weber *et al.* (Weber, Peters et al. 2008), we could find some differences. Not alike the way they think one major player could be exports (one third contribution in 2005, as shown in their paper); we argue the GHG (not include SO2) emissions are mainly yielded by domestic economic activities (more than 85%, not only CO2 but also SO2 and NOx, as can be found in Table1) since processing exports are major part of China's exports which emit less.

While the other side of the coin is economic benefit gains from performing processing exports. It is relatively low in comparison with non-processing ones. However, if we take a closer look at Table 4 of the ratios, we may get clear picture of trade-off between worse environment protection (pains) and (more) value added (gains), and *vice versa*. Nonetheless, on average promoting processing exports is still one good option to some extent currently.

5. Discussion and policy recommendations

As is known to all, economics is dealing with scarcity. So people always have to face some options to choose and they have to pay opportunity cost for selecting one over another. The same holds for a country, as a developing country some people may argue it could be possible to develop economy at the cost of environment, while others stress the importance of sustainable development, i.e. balancing economic growth and environment protection. In consequence, developing countries are facing the trade-off between GHG emissions and value added to be explicit.

Recall that processing exports generate less economic benefit as well as less (domestic) GHG emissions. An implicit assumption lies behind here, which is that if we were producing the imported intermediate goods at home, they would yield more GHG emission given that we have lower level of technique condition. Thus, from China's point of view, it would be more interesting to detect how much less pollution will be attained given the same amount of export value if we produce processing type rather than non-processing type. In the same fashion, the policy maker may concern about how much more processing exports has to be produced in order to achieve some economic goal as compared with non-processing activity taking into account the relatively lower value added coefficient. It is not difficult to find that, on average, conducting processing exports is the most efficient way (with smallest cost for given value added generation, no matter which average is taken, as shown in Table 4), while non-processing activity for domestic use purposes performs worst in terms of efficiency (see Table 4).

Since China is a somehow "dual-track" economy (Lau, Qian et al. 2000), the policy still plays important role in industry performance. In this respect, we would recommend some strong policy to regulate those highly polluted industries, like "electricity and heating power production and supply" who continues the situation of coal-dominating production pattern (around 70% since 1970s, as suggested in Figure 4), and also sectors 13, 14 and 23 who are inefficient (for detailed results please see Table 4). As those measures given in Weber *et al.* (Weber, Peters et al. 2008) such as upgrading techniques, installing more renewable power and so forth. In contrast, for those "clean" industries, it is suggested to provide policy support by allowing production increasing, tax favor and so on.

This paper also shows an example to estimate the export's contribution both to climate change and economic growth precisely. The methodology applies to those developing countries performing considerable share of processing trade.

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Appendix A. Industry classification

Number	Description
1	Agriculture
2	Coal mining, washing and processing
3	Crude petroleum and natural gas products
4	Metal ore mining
5	Non-ferrous mineral mining
6	Manufacture of food products and tobacco processing
7	Textile goods
8	Wearing apparel, leather, furs, down and related products
9	Sawmills and furniture
10	Paper and products, printing and record medium reproduction
11	Petroleum processing, coking and nuclear fuel processing
12	Chemicals
13	Nonmetal mineral products
14	Metals smelting and pressing
15	Metal products
16	Common and special equipment
17	Transport equipment
18	Electric equipment and machinery
19	Telecommunication equipment, computer and other electronic equipment
20	Instruments, meters, cultural and office machinery
21	Other manufacturing products
22	Electricity and heating power production and supply
23	Gas production and supply
24	Water production and supply
25	Construction
26	Transport and warehousing
27	Wholesale and retail trade
28	Services

Appendix B. Proof of equation (6)

From figure 2 and figure 3, we have

$$\mathbf{Z} = \mathbf{Z}^{DD} + \mathbf{Z}^{ND} + \mathbf{Z}^{DP} + \mathbf{Z}^{NP} + \mathbf{Z}^{DN} + \mathbf{Z}^{NN}$$

and

$$\begin{aligned} <\mathbf{s}'\mathbf{Z}> &= <\mathbf{s}'(\mathbf{Z}^{\mathbf{DD}} + \mathbf{Z}^{\mathbf{ND}} + \mathbf{Z}^{\mathbf{DP}} + \mathbf{Z}^{\mathbf{NP}} + \mathbf{Z}^{\mathbf{DN}} + \mathbf{Z}^{\mathbf{NN}})> \\ &= <\mathbf{s}'(\mathbf{Z}^{\mathbf{DD}} + \mathbf{Z}^{\mathbf{ND}})> + <\mathbf{s}'(\mathbf{Z}^{\mathbf{DP}} + \mathbf{Z}^{\mathbf{NP}})> + <\mathbf{s}'(\mathbf{Z}^{\mathbf{DN}} + \mathbf{Z}^{\mathbf{NN}})> \end{aligned}$$

where s' is a summation vector with ones, $<\mathbf{y}>$ is used to indicate the diagonal matrix obtained from the vector **y** in case **y** is the product of a matrix and a vector.
Since $\mathbf{Z} = \mathbf{A}\hat{\mathbf{x}}$, $\mathbf{Z}^{\mathbf{RS}} = \mathbf{A}^{\mathbf{RS}}\hat{\mathbf{x}}^{\mathbf{S}}$, we have

$$<\mathbf{s}'\mathbf{A}>\hat{\mathbf{x}} = <\mathbf{s}'(\mathbf{A}^{\mathbf{DD}} + \mathbf{A}^{\mathbf{ND}})>\hat{\mathbf{x}}^{\mathbf{D}} + <\mathbf{s}'(\mathbf{A}^{\mathbf{DP}} + \mathbf{A}^{\mathbf{NP}})>\hat{\mathbf{x}}^{\mathbf{P}} + <\mathbf{s}'(\mathbf{A}^{\mathbf{DN}} + \mathbf{A}^{\mathbf{NN}})>\hat{\mathbf{x}}^{\mathbf{N}}$$

According to equation (5), $\hat{\boldsymbol{\mu}} = <\mathbf{s}'\mathbf{A}><\mathbf{s}'(\mathbf{A}^{\mathbf{DR}} + \mathbf{A}^{\mathbf{NR}})>^{-1}\hat{\boldsymbol{\mu}}^{\mathbf{R}}$, with $R = D, P, N$

Multiplying both sides with $\hat{\boldsymbol{\mu}}<\mathbf{s}'\mathbf{A}>^{-1}$ gives

$$\hat{\boldsymbol{\mu}}\hat{\mathbf{x}} = \hat{\boldsymbol{\mu}}^{\mathbf{D}}\hat{\mathbf{x}}^{\mathbf{D}} + \hat{\boldsymbol{\mu}}^{\mathbf{P}}\hat{\mathbf{x}}^{\mathbf{P}} + \hat{\boldsymbol{\mu}}^{\mathbf{N}}\hat{\mathbf{x}}^{\mathbf{N}}$$

which completes the proof.

Figure 1. Historical trend of processing exports share (% of total exports): 1981-2007

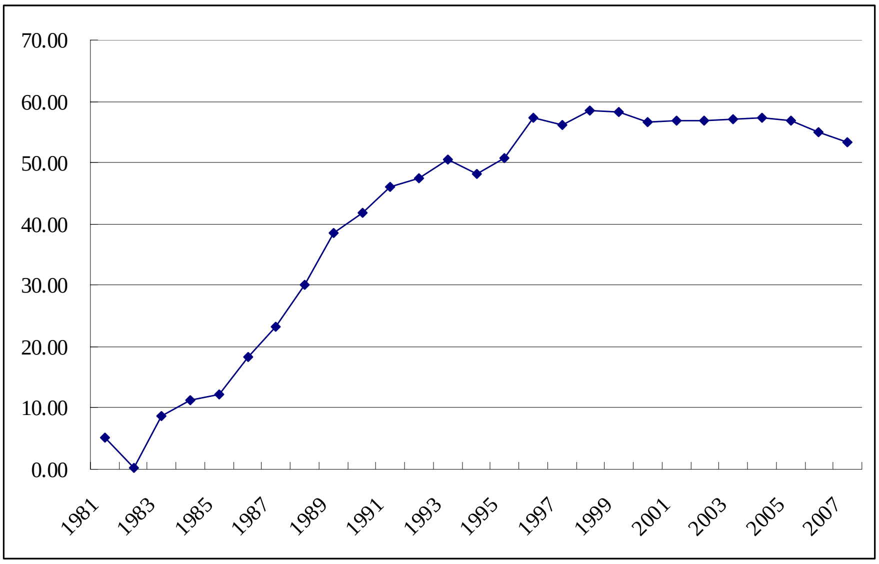


Figure 2. The structure of China's tripartite input-output table, including processing trade

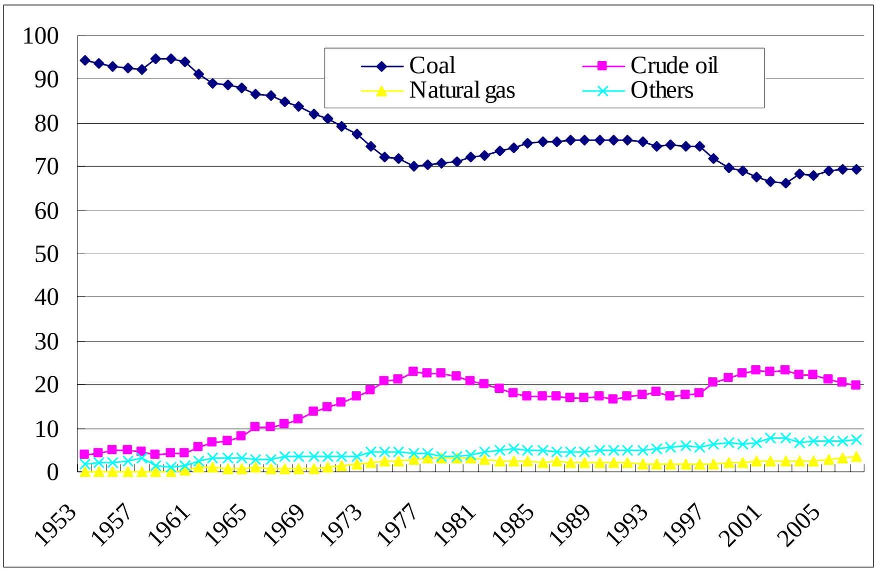
	Intermediate use			Final use		
	D	*P*	*N*	*DFD*	*EXP*	*TOT*
D	$\mathbf{Z}^{DD}$	$\mathbf{Z}^{DP}$	$\mathbf{Z}^{DN}$	$\mathbf{f}^{D}$	0	$\mathbf{x}^{D}$
P	0	0	0	0	$\mathbf{e}^{P}$	$\mathbf{x}^{P}$
N	$\mathbf{Z}^{ND}$	$\mathbf{Z}^{NP}$	$\mathbf{Z}^{NN}$	$\mathbf{f}^{N}$	$\mathbf{e}^{N}$	$\mathbf{x}^{N}$
IMP	$\mathbf{M}^{D}$	$\mathbf{M}^{P}$	$\mathbf{M}^{N}$	$\mathbf{f}^{M}$	0	$\mathbf{x}^{M}$
VA	$(\mathbf{v}^{D})'$	$(\mathbf{v}^{P})'$	$(\mathbf{v}^{N})'$			
TOT	$(\mathbf{x}^{D})'$	$(\mathbf{x}^{P})'$	$(\mathbf{x}^{N})'$			

Notes: *D* = industries producing for domestic use; *P* = industries producing processing exports; *N* = industries producing non-processing exports and other production of foreign-invested enterprises; *DFD* = domestic final demand; *EXP* = exports; *TOT* = gross industry outputs (and total imports in the column *TOT*); *IMP* = imports; and *VA* = value added.

Figure 3. The structure of China's 'ordinary' national input-output table

	Intermediate use	Final use		
		DFD	*EXP*	*TOT*
	$\mathbf{Z}$	$\mathbf{f}$	$\mathbf{e}$	$\mathbf{x}$
IMP	$\mathbf{M}$	$\mathbf{f}^{M}$	0	$\mathbf{x}^{M}$
VA	$\mathbf{v}'$			
TOT	$\mathbf{x}'$			

Figure 4. Composition of China's primary energy consumption (%): 1953-2007



Note: **Others** refer to *hydroelectric power*, *nuclear power*, and *wind power* etc.

Table 1. Overview of results at the aggregate level, emissions and values added per final demand category

	Tripartite IO table				Ordinary IO table	
	Domestic		Exports		Domestic	Exports
	D	*N*	*P*	*N*		
	(4a)	(4b)	(4c)	(4d)	(2a)	(2b)
CO_2						
separate coeffs	2512.84	463.98	71.30	358.19	2716.01	690.30
(%)	(73.77)	(13.62)	(2.09)	(10.52)	(79.73)	(20.27)
identical coeffs	2498.31	443.85	96.07	368.09		
(%)	(73.34)	(13.03)	(2.82)	(10.81)		
SO_2						
separate coeffs	19289.24	3818.54	481.05	2650.48	20823.31	5415.91
(%)	(73.51)	(14.55)	(1.83)	(10.10)	(79.36)	(20.64)
identical coeffs	19188.60	3648.37	657.76	2744.58		
(%)	(73.13)	(13.90)	(2.51)	(10.46)		
NO_x						
separate coeffs	9013.47	2023.52	308.37	1484.40	10175.49	2654.23
(%)	(70.25)	(15.77)	(2.40)	(11.57)	(79.31)	(20.69)
identical coeffs	9122.67	1873.64	376.66	1456.79		
(%)	(71.11)	(14.60)	(2.94)	(11.35)		
Value added						
nominal	9847.47	719.59	373.70	1245.13	9837.54	2348.35
(%)	(80.81)	(5.90)	(3.07)	(10.22)	(80.73)	(19.27)

Notes: CO_2 emissions are in Mt, SO_2 and NO_x emissions are in kt, and values added are in billion Rmb

Table 2. CO_2 emissions (Mt) in each industry, per final demand category

	Domestic		Exports		
	D	*N*	*P*	*N*	
Industry	(4a)	(4b)	(4c)	(4d)	Total
1	72.78	3.86	1.10	7.36	85.1
2	26.39	4.81	0.94	5.44	37.58
3	37.71	3.72	0.49	4.84	46.76
4	5.73	0.09	0.08	0.21	6.11
5	6.75	0.09	0.15	0.61	7.6
6	29.86	5.52	0.76	3.56	39.7
7	13.58	0.68	1.64	10.84	26.74
8	0.97	0.07	0.19	0.50	1.73
9	3.08	0.51	0.20	0.77	4.56
10	17.27	1.61	1.95	2.97	23.8
11	44.66	1.77	0.82	3.71	50.96
12	149.01	8.91	7.30	20.30	185.52
13	451.27	39.87	9.34	50.27	550.75
14	376.89	25.18	4.69	36.08	442.84
15	8.52	0.42	0.32	1.58	10.84
16	18.20	2.63	0.41	1.55	22.79
17	10.03	1.19	0.27	0.96	12.45
18	4.02	0.07	0.28	0.49	4.86
19	4.16	0.05	0.22	0.27	4.7
20	0.31	0.06	0.42	0.26	1.05
21	5.14	0.27	0.32	0.94	6.67
22	963.33	347.63	25.26	157.15	1493.37
23	3.53	0.60	0.12	0.84	5.09
24	0.33	0.16	0.02	0.02	0.53
25	22.44	0.09	0.04	0.22	22.79
26	153.24	9.26	9.74	35.72	207.96
27	23.00	1.52	2.96	5.79	33.27
28	60.65	3.35	1.26	4.95	70.21
Total (%)	2512.84 (73.77)	463.98 (13.62)	71.30 (2.09)	358.19 (10.52)	3406.31 (100.00)

Table 3. Value added (billion Rmb) in each industry, per final demand category

	Domestic		Exports		
	D	*N*	*P*	*N*	
Industry	(4a)	(4b)	(4c)	(4d)	Total
1	1422.21	75.51	21.55	143.77	1663.05
2	160.12	29.18	5.70	33.02	228.02
3	187.19	18.46	2.42	24.02	232.10
4	58.69	0.93	0.77	2.15	62.53
5	65.76	0.90	1.41	5.94	74.01
6	338.23	62.57	8.61	40.32	449.72
7	113.28	5.70	13.72	90.42	223.13
8	91.55	6.53	17.86	47.03	162.97
9	72.75	12.06	4.80	18.14	107.75
10	172.18	16.01	19.46	29.63	237.28
11	91.70	3.64	1.68	7.61	104.64
12	466.58	27.90	22.87	63.58	580.93
13	156.40	13.82	3.24	17.42	190.87
14	319.10	21.32	3.97	30.54	374.93
15	111.60	5.46	4.17	20.75	141.97
16	291.50	42.05	6.61	24.77	364.93
17	203.75	24.10	5.55	19.52	252.92
18	141.99	2.50	10.06	17.36	171.91
19	241.83	2.64	12.77	15.56	272.80
20	12.87	2.35	17.51	10.72	43.46
21	44.46	2.33	2.75	8.12	57.66
22	255.61	92.24	6.70	41.70	396.24
23	5.15	0.87	0.17	1.23	7.41
24	18.01	8.60	0.86	0.88	28.35
25	649.30	2.57	1.16	6.39	659.42
26	502.67	30.39	31.96	117.17	682.19
27	641.74	42.51	82.57	161.41	928.23
28	3011.29	166.43	62.79	245.97	3486.47
Total (%)	9847.47 (80.81)	719.59 (5.90)	373.70 (3.07)	1245.13 (10.22)	12185.88 (100)

Table 4. Cost-benefit ratios of final demands for product i, per class of production

Product i	D	P	N	
1	0.15	0.12		0.14
2	0.36	0.21		0.40
3	0.32	0.22		0.36
4	0.43	0.21		0.54
5	0.31	0.19		0.35
6	0.18	0.16		0.17
7	0.26	0.20		0.26
8	0.18	0.15		0.18
9	0.25	0.18		0.24
10	0.26	0.19		0.25
11	0.40	0.33		0.49
12	0.44	0.33		0.50
13	1.45	1.36		1.61
14	0.81	0.57		0.91
15	0.50	0.22		0.52
16	0.36	0.20		0.40
17	0.32	0.20		0.32
18	0.36	0.21		0.38
19	0.26	0.22		0.32
20	0.22	0.14		0.23
21	0.30	0.21		0.29
22	2.26	2.21		2.35
23	0.50	0.41		0.54
24	0.45	0.15		0.59
25	0.43	0.29		0.43
26	0.33	0.30		0.33
27	0.15	0.11		0.15
28	0.15	0.10		0.14
Averages	Domestic	Exports	Domestic	Exports
Value added shares, equation (7)	0.26	0.19	0.64	0.29
Final demand shares, equation (8)	0.26	0.21	0.61	0.32
Harmonic mean, equation (9)	0.20	0.18	0.27	0.24