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Kiel Institute for the World Economy, Hindenburgufer 66, 24105 Kiel, Germany

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Emissions embodied in Chinese exports taking into account the special export structure of China*

Matthias Weitzel and Ma Tao

Abstract:
Quantification of CO_2 emissions embodied in China's trade is important for an informed debate on whom to blame for the recent rise in Chinese emissions or the calculation of border carbon adjustments. Applying input output techniques, we calculate these emissions in (1) a standard model, (2) a regionally disaggregated model, taking into account that export production is concentrated in more advanced and more emission efficient provinces and (3) in a model with export processing, taking into account that almost half of Chinese exports relies on a large share of imported intermediates and little domestic value and emissions added. We compare year 2007 emissions embodied for in Chinese exports in a unified framework. We also report emissions embodied in Chinese imports used for intermediate production of exports by combining calculations for China with data from global IO models. We find that both a model with 30 provinces (1730 Mt CO_2) and a model accounting for export processing (1580 Mt) yield lower Chinese emissions embodied in exports compared to the standard model (1782 Mt). In the regional model, emissions are even lower (1522 Mt), if interprovincial trade is not taken into account.

Keywords: Emissions embodied in trade, China, input-output modelling, export processing, spatial disaggregation

JEL classification: C67, F18, Q54

Matthias Weitzel
Kiel Institute for the World Economy
24100 Kiel, Germany
Telephone: +49-(0)431-8814-580
E-mail: matthias.weitzel@ifw-kiel.de

Ma Tao
Institute of World Economics and Politics
Chinese Academy of Social Sciences
No. 5 Jianguomennei St.
Beijing, China, 100732
E-mail: matao@cass.org.cn

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1 Introduction

China has become the world's largest emitter of CO_2 in 2006, and in 2012 Chinese emissions already accounted for 29% of global emissions (Olivier et al., 2013). A substantial share of these emissions is associated with the production of export goods, because for a large economy China has a very high export share in GDP. Both the absolute number of CO_2 emissions embodied in Chinese exports as well as the share of emissions associated with export production in total Chinese emissions has risen over time (Weber et al., 2008; Peters et al., 2011; Zhang, 2012), driven by a growth rate of trade that exceeds overall GDP growth rates (Wei et al., 2011).

The quantification of emissions embodied in Chinese exports is partly rooted in a discussion on who is responsible for the rise in Chinese emissions (Pan et al., 2008). From the Chinese perspective, these emissions could be attributed to foreign consumption and thus are not (exclusively) subject to the Chinese responsibility. From a developed countries different perspective, these emissions can however also be viewed as leakage arising from emission constraints. Countermeasures for leakage such as border carbon adjustments could therefore target these emissions embodied in trade. A calculation of the emissions at stake could thus inform this political discussion.

The emissions embodied in China's exports are subject to several input-output (IO) analyses of a single country (e.g. Su and Ang, 2010; Weber et al., 2008; Zhang, 2012), of bilateral trade flows (e.g. Guo et al., 2010), or of multiple regions (MRIO) (e.g. Atkinson et al., 2011; Peters et al., 2011; Davis et al., 2011). Previous studies often assume that the structure of the export production and production for domestic use is identical. In reality however, Chinese exports are produced mainly in energy and emission efficient coastal provinces and a sizable fraction comes from "export processing" where little value and energy is added in China.

China is very diverse regionally, both in terms of income and efficiency in production, but also in terms of the share of exports in GDP. Exports are regionally concentrated in the more advanced provinces. The coastal provinces of Jiangsu, Guangdong, Shanghai, and Zhejiang alone contributed 69% of Chinese exports in 2007 (National Bureau of Statistics of China, 2009b). To determine the emissions embodied in exports, the economic structure of these provinces is important. Emission intensity (emissions per unit of value added) in these provinces is lower than the average for China. Recent studies calculating emissions embodied in Chinese exports based on a regionally disaggregated IO model find indeed lower emissions compared to a standard model (Su and Ang, 2010; Guo et al., 2012). Interprovincial trade plays however an important role in China, and provinces with a high share of export production are net receivers of emissions embodied in domestic trade (Feng et al., 2013; Guo et al., 2012). In this study we therefore want to analyze how export concentration in carbon efficient provinces on the one hand and interprovincial trade on the other hand offset each other.

At the same time, about half of the export production is carried out under "export processing" provisions, i.e. provisions that stipulate production in "customs special supervision zones" where imported intermediate inputs enjoy a preferential treatment. Export processing is thus characterized by a high share of imported intermediates and a low share of Chinese value added (Koopman et al., 2008). Recent studies find that emission especially in the export processing sectors are much lower than if average domestic production technology is assumed (Ma, 2012; Dietzenbacher et al., 2012; Su et al., 2013).

In this study we extend the standard IO model to calculate emissions embodied in exports by relaxing the assumption of homogenous production functions for all output in a given sector. We model export sectors differently and compare this to the standard calculation of emissions embodied in trade in two ways: First a spatial disaggregation and second a special treatment of the export processing sector. For the spatial disaggregated model, we specifically discuss the role of emissions embodied in interprovincial trade. For a consistent comparison, we carry out out analysis in a unified mathematical framework and balance disaggregated IO tables in a way that a re-aggregation would yield the national IO table. Furthermore, we base all our calculations on 2007 IO tables and thus provide an update of previous studies that compare regionally disaggregated models or models with export processing.

China is not only characterized by a high share of exports in GDP, but also by a high share of imports in GDP. Consequently, emissions embodied in imports which are used as intermediate inputs in the production of export goods are not negligible. Previous studies often used Chinese domestic technology assumption to calculate these emissions. Emission intensities of Chinese imports are however lower than of its own production. Differences in efficiency between countries were usually corrected for only in simplified ways if at all. To improve the depiction of these emissions, we combine our analysis of Chinese IO models with data derived from a global MRIO model based on GTAP data (Narayanan et al., 2012).

Our main aim in the comparison of the three IO models is to determine the magnitude of differences in the estimates for emissions embodied in Chinese exports and Chinese domestic final use. If there is only little change in the more complex models relative to the simpler national model, then a national model can be seen as a justified approximation in future applications. However, the more detailed models can also provide valuable insights to better understand where (in what provinces) and how (export processing vs. normal exports) emissions embodied in exports are originated. This can provide guidance to design emission reduction policies.

The article is structured as follows: Sections 2 – 4 present an IO model in a standard way, with spatial disaggregation, and a separate export processing sector, respectively. Section 5 presents and compares results from the different models. Section 6 concludes.

2 Standard input-output approach to calculate emissions embodied in exports

In the standard input-output model, total output X is the sum of intermediate production Z and final demand Y

$$X = Z + Y = AX + Y = (I - A)^{-1}Y \tag{1}$$

with the production coefficient matrix $A = \frac{Z}{diag(X)}$ and the Leontief inverse $(I - A)^{-1}$ indicating total production requirements for one unit of final output.[1] To obtain CO_2 emissions C associated with the final use of Y, the production requirements to produce Y have to be multiplied with with the environmental coefficient vector F with elements $f_i = c_i/x_i$, with c_i being the total direct emissions of production x_i in each sector i.

$$C = F'(I - A)^{-1}Y. \tag{2}$$

The final demand vector Y consists of domestic demand and exports E. Accordingly, the emissions associated with the production of export demand are then

$$C^E = F'(I - A)^{-1}E. \tag{3}$$

Chinese input output tables assume competitive import assumption, i.e. the technology matrix A consists of both domestically produced and imported intermediate inputs $A = A^D + A^M$. By replacing A with $A^D + A^M$, Su and Ang (2013, Appendix A) show that emissions in export can be re-written as

$$C^E = F'(1 - A^D)^{-1}E + F'(I - A)^{-1}A^M(1 - A^D)^{-1}E. \tag{4}$$

The first term gives domestic emissions in exports while the second term describes the emissions embodied in imported intermediate inputs required for export production. Replacing the total emission intensity for imported goods $F'(I - A)^{-1}$ with $F^{M'}$, domestic and imported emissions embodied in exports can can be denoted by

$$C^{D,E} = F'(I - A^D)^{-1}E \tag{5}$$

and

$$C^{M,E} = F^{M'}A^M(I - A^D)^{-1}E. \tag{6}$$

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[1] Matrices and vectors are denoted by capital letters, while scalars such as elements of matrices are denoted with lower case.

This allows also for calculation of emissions associated with Chinese domestic final use by subtracting emissions embodied in exports from total (direct, energy related) emissions in China $C_{prod} = \sum_i c_i$ and adding emissions embodied in total imports $C^M = F^{M\prime} M$. This leads to consumption based rather than production accounting of Chinese emissions:

$$C^D_{cons} = C_{prod} + C^M - (C^{D,E} + C^{M,E}) \tag{7}$$

3 Embodied emissions in exports with spatial disaggregation

For the spatial disaggregation we use the same concept as above, however now matrix A^D and vectors F and E have different dimensions. While the dimensions in the standard model were determined by the numbers of sectors, the regionally disaggregated model now has the dimensions of the number of sectors n times the number of regions m. We construct a Chenery-Moses interregional IO matrix:

$$A^{D*} = \begin{pmatrix} A^D_1 & 0 & \cdots & 0 \\ 0 & A^D_2 & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & A^D_m \end{pmatrix}$$

where A^D_k is the $n \times n$ use matrix of the k^{th} province. To obtain A^{D*}, we split total regional inflows provided in the data into imports from abroad and inflows from other provinces using an entropy method (Robinson et al., 2001) and then remove imports from foreign as in the section above to obtain A^D_k.

If A^{D*} were directly used in the IO analysis, all domestic intermediate inputs are originating in the region. To incorporate interprovincial trade flow, we pre-multiply A^{D*} with a transfer matrix T. This Chenery-Moses transfer matrix T is structured as follows

$$T = \begin{pmatrix} T_{1,1} & T_{1,2} & \cdots & T_{1,m} \\ T_{2,1} & T_{2,2} & \cdots & T_{2,m} \\ \vdots & \vdots & \ddots & \vdots \\ T_{m,1} & T_{m,2} & \cdots & T_{m,m} \end{pmatrix}$$

The diagonal submatrix $T_{r,s}$ contains elements $t_{i,r,s}$ stating the share of good i traded from region r to region s in total use of good i in region s. For the special case where T is the identity matrix, there is no interprovincial trade.

The equations for calculating Chinese (domestic) emissions and imported emissions embodied in exports are

$$C^{D,E} = F'(I - TA^{D^*})^{-1}E \tag{8}$$

and

$$E^{M,E} = F^{M'}A^M(I - TA^{D^*})^{-1}E. \tag{9}$$

The vector $F^{M'}$ is an m times stacked vector $F^{M'}$ from equation 6 above, i.e. import emission intensities are not differentiated by origin. The national emission intensity vector F' is calculated with provincial energy data, however scaled such that the sum is equal to the sum of national emissions.

4 Emissions embodied in trade with disaggregated export processing sector

An alternative method to improve the representation of the exports is the introduction of export processing sectors. As the spatial disaggregation method, this approach also splits the national IO table based on additional information. Here, this additional information comes from Chinese customs data and allows for better representation of imports and domestic intermediates (and value added) in export production. The split of the underlying national IO table was first proposed by Koopman et al. (2008) to determine the

Chinese domestic value added share of Chinese exports and adapted to environmental IO modeling by Ma (2012), Dietzenbacher et al. (2012) and Su et al. (2013).

The intuition is to split the input-output table into (a) "normal" production sectors N for regular production to fulfill Chinese demand for domestic products Y^D and foreign demand for non-processing exports E^N and (b) into sectors P for processing exports E^P. These export processing sectors are not producing any output that is used as intermediate input or domestic final consumption, however, goods produced in the regular production sector N can be used as intermediate input in the export processing sector (A^{NP}). The model from equation 1 is therefore more complex:

$$\begin{bmatrix} X - E^P \\ E^P \end{bmatrix} = \begin{bmatrix} A^{NN} & A^{NP} \\ 0 & 0 \end{bmatrix} \begin{bmatrix} X - E^P \\ E^P \end{bmatrix} + \begin{bmatrix} Y^D + E^N \\ E^P \end{bmatrix} \tag{10}$$

where A^{NN} are intermediates both produced and used in N. Solving the model for the output vector yields

$$\begin{aligned} \begin{bmatrix} X - E^P \\ E^P \end{bmatrix} &= \begin{bmatrix} I - A^{NN} & -A^{NP} \\ 0 & I \end{bmatrix}^{-1} \begin{bmatrix} Y^D + E^N \\ E^P \end{bmatrix} \\ &= \begin{bmatrix} (I - A^{NN})^{-1} & (I - A^{NN})^{-1} A^{NP} \\ 0 & I \end{bmatrix} \begin{bmatrix} Y^D + E^N \\ E^P \end{bmatrix} \end{aligned} \tag{11}$$

and the production requirements for the normal sector

$$X - E^P = (I - A^{NN})^{-1}(Y^D + E^N) + (I - A^{NN})^{-1} A^{NP} E^P. \tag{12}$$

Pre-multiplying with the environmental intensity vector F^N, dropping the domestic demand Y^D and adding direct emissions from the export processing sector ($F^{P'}E^P$) yields an equation similar to equation 3 which states the Chinese emissions associated with the production of exports.[2]

$$C^{D,E} = F^{N\prime}(I - A^{NN})^{-1}E^{N} + F^{N\prime}(I - A^{NN})^{-1}A^{NP}E^{P} + F^{P\prime}E^{P}. \tag{13}$$

The first term provides the emissions associated with domestic emissions from the regular (export) production sector. The second term provides indirect emissions of the export processing sectors, associated with domestic intermediates that enter the export processing sector. The third term finally provides direct emissions in the export processing sector.

In order to calculate the emissions embodied in exports associated with imports to China, we use the fact that all imports not for final consumption have to enter intermediate production either in the regular domestic sector or in the export processing sector:

$$M - Y^{M} = A^{MN}(X - E^{P}) + A^{MP}E^{P} \tag{14}$$

Replacing $X - E^{P}$ with the expression from 12 and again dropping domestic demand, we can calculate the import requirements for export production:

$$M^{E} = A^{MN}[(I - A^{NN})^{-1}E^{N} + (I - A^{NN})^{-1}A^{NP}E^{P}] + A^{MP}E^{P} \tag{15}$$

By pre-multiplying the environmental intensity vector of the imported goods $F^{M\prime}$, we can now calculate the emissions associated with imported intermediates that are embodied in Chinese exports.

$$C^{M,E} = F^{M\prime}A^{MN}(I - A^{NN})^{-1}E^{N} + F^{M\prime}A^{MN}(I - A^{NN})^{-1}A^{NP}E^{P} + F^{M\prime}A^{MP}E^{P} \tag{16}$$

The first term describes emissions associated with exports from the normal production sector while the second and third term describe the indirect and direct emissions from imports in the export processing sector, respectively.[3]

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[2] Note that there are two intensity vectors F^{N} and F^{P}. Direct emissions in P stem from use of energy goods as intermediates.

[3] Direct here refers to imported intermediates that are directly used in the export processing sector, while indirect refers to imported intermediates that are required for production of domestic intermediates

5 Results

We now fill the theoretical model with data from the Chinese IO tables for 2007. For models which relax the assumption of homogeneity in the domestic and export sectors, we augment the data from the IO table with additional information taken from provincial IO tables, energy consumption data and information on international and interprovincial trade for the regionally disaggregated model flows or with customs data for export processing trade model, respectively. All disaggregated models are calibrated such that a re-aggregation would result in the national IO table. Appendices A.1 – A.3 describe the steps taken for the different models in more detail.

In all models, total direct emissions (including residential use) are 5513 Mt. CO_2. Emissions embodied in imports are 301 Mt. The emissions embodied in imports are much lower than comparable studies because the emission intensity is not calculated assuming Chinese production technology, but by using emission intensity from a MRIO model based on the GTAP dataset.

Table 1 reports emissions embodied in exports and imports as well as emissions associated with Chinese final use. In the standard IO model based on the national IO table, domestic emissions embodied in exports amount to 1782 Mt CO_2, i.e. about 32% of domestic emissions result from the production of export goods. In addition, 97 Mt of the emissions embodied in imports are re-exported. This is also about one third of all emissions embodied in imports. China therefore is a net exporter of 1674 Mt CO_2. The similar share is due to the assumption of proportionality of imports in all use categories. Adding imported emissions to and subtracting exported emissions from the direct production emissions yields emissions embodied in Chinese final use. These emissions amount to 4190 Mt.

In the regional model without interregional trade, emissions embodied in exports are 260 Mt. lower than in the national model. This model takes into account that export production is concentrated in coastal provinces of China which are producing with a lower

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with then enter the export processing sector.

IO Model	Chinese (domestic) emissions embodied in exports (A)	Emissions from imported intermediated embodied in exports (B)	Total emissions embodied in exports (C=A+B)	Domestic emissions for domestic final demand (D)	Emissions embodied in imports not used for export production (E)	Total emissions from domestic final demand (F=D+E)
Standard	1782	97	1879	3985	205	4190
Regional Disaggregation (no interprovincial trade)	1522	104	1627	4245	197	4441
Regional Disaggregation (with interprovincial trade)	1730	96	1826	4037	206	4242
Export Processing (normal+ processing)	1226+354 =1580	30+107 =137	1256+460 =1716	4188	165	4352

Table 1: Emissions embodied in Chinese trade and consumption (in Mt. CO_2). Summations might differ due to rounding.

emission intensity. Emissions associated with imported goods for export production in contrast is slightly higher than in the national model because the export intensive provinces are also the provinces with a higher import share. Compared to the national model, emissions embodied in exports are 13% lower, but emissions embodied in final use are 6% higher.

Taking into account interprovincial trade, much of this difference between the regional and the national model disappears. Export intensive provinces are importing a considerable share of intermediate goods from other provinces. Since these provinces are less emission intensive, total emission intensity in exporting provinces increases. Overall there is a converges of emission intensities between provinces. As for the national model, there is a proportionality assumption, hence for each province the share of imported good use as intermediate goods is equal to the share in other final demand.

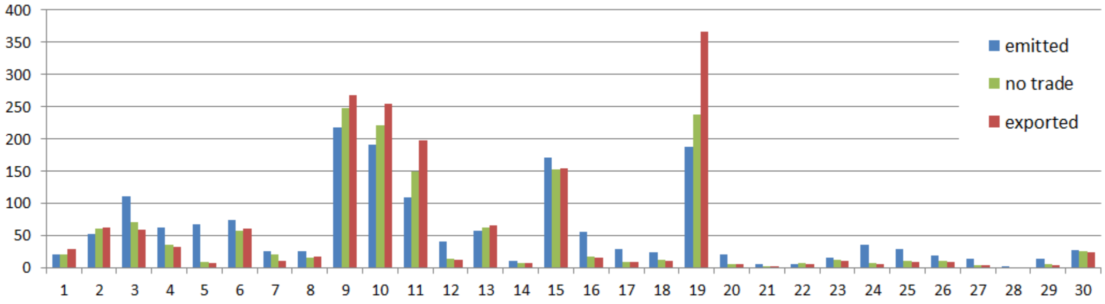

Figure 1: Domestic emissions embodied in exports by province (in Mt CO_2). Province names in Appendix A.4.

Taking a closer look at the regional model, we can analyze emissions in the different provinces. Figure 1 shows domestic emission embodied in exports by province. Emissions are attributed either to where thy are added in the production chain (i.e. the location in which the emissions were released into the atmosphere, blue bars) or to where the final export good is produced (red bars). In the scenario without interprovincial trade (green bars), both calculations yield the same provincial emissions.[4] It can be seen that the top exporting provinces Shanghai (province 9), Jiangsu (10), Zhejiang (11), and Guangdong (19) account for the most emissions embodied in exports.[5] In the western provinces (20 through 30) on the other hand contribute relatively little Chinese emissions in exports. There are however substantial differences between scenarios. When emissions are accounted for where the final export product is assembled, these emissions are highest for the top exporters, because all emissions along the value chain are accounted for in the final production step. If emissions are however accounted at the stage where they are released into the atmosphere, the picture changes and the emissions released in the top exporting provinces are lower. On the other hand, provinces which provide energy intensive intermediates (such as electricity, steel etc.) now account for higher emissions embodied in exports. This very obvious for Inner Mongolia (5) which has very little exports, but some of its energy intensive production ends up in exports. Emissions embodied in exports in the scenario without interprovincial trade usually lies

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[4] Note that while the sums of the first two calculations are identical (blue and red bars), the sum of the model without interprovincial trade is lower (green bars, cf. also Table 1).

[5] While Shanghai is exporting a lot, there might be some statistical problems when exports are accounted for Shanghai because they are shipped from Shanghai, although production might not necessarily be located in Shanghai. The data used accounts for differences in production and export location but this might be difficult to distinguish, especially when in addition there are company headquarters also located in Shanghai.

between other two reported emissions in the scenario with trade. Shandong (15), which also ranks among the provinces with the highest emissions in exports, does not show this variation between the different accounting methods. For Shandong emissions are relatively constant because its emission intensity is higher than the other top exporting provinces and there is less (net) inflow of intermediate inputs for export production.

Turning to the model with a separate export processing sector, emissions embodied in exports again are lower than in the national model. With 1716 Mt, total emissions embodied in exports are also below the regionally disaggregated model with interprovincial trade. The share of imports that is used as input in the export processing sector is higher than in the other models, resulting in higher emissions embodied in imports for export production (137 Mt). Although the export processing sector accounts for 42% of the export value, it contributes only 22% of domestic emissions in all exports. Because imports are used as intermediate inputs for export processing in a higher proportion, there are less imports used as intermediates in the domestic sector. This results in higher emission intensities in the domestic sector and exports from the normal sector embody 1226 Mt. CO_2. As emissions embodied in exports are lower than in the national and the regionally disaggregated model with interprovincial trade, emissions embodied in Chinese final consumption are consequently higher.

The emissions embodied in exports can be decomposed (cf. equation 13 and 16). Figure 2 presents this decomposition for the different sectors. The direct emissions added in export processing are very small (29 Mt) and the majority of emissions embodied in exports from the processing sector comes from intermediates produced in the domestic sector. In electronics sector (sector 19), 89% of exports stem from from the processing sector. Because the export processing sector is using many imports, emissions embodied in imports are relatively high in this sector and consequently domestic emissions are relatively low.

Comparing sectoral emissions in the different models, gives an indication in which sectors the differences between the model versions arise. Figure 3 shows that there is no clear ranking between the sectors across different IO models. Compared to the national

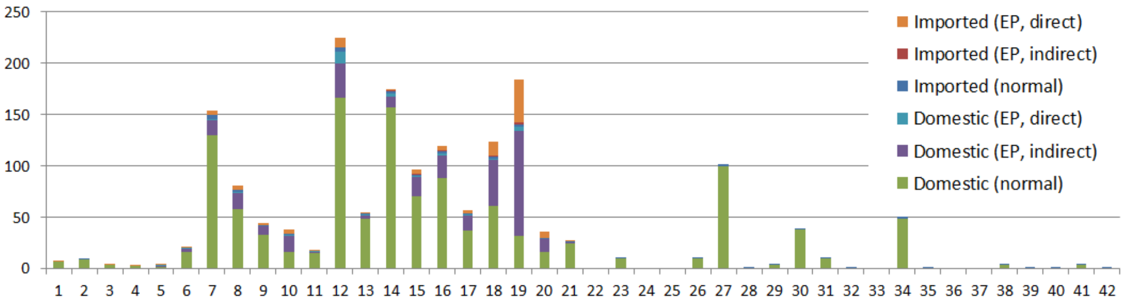

Figure 2: Emissions embodied in exports by sector and channel taking into account export processing (in Mt CO_2). Sector codes in Appendix A.5.

model, the regionally disaggregated model indicates lower emissions embodied in sectors chemicals (12), metals (14), machinery (16), and electric equipment and machinery (18), but higher emissions in sectors 19 and 27. The higher emissions in the transport sector (27) are due to a concentration of export activity in this sector in Shanghai. Because Shanghai has a higher emission intensity compared to the national average, emissions in this sector are high. For the electronics sector (19), which also has a higher amount of embodied emissions, it is more difficult to find a driver as export production is more spread between different provinces. The export processing model has lower emissions in sectors with a high share of export processing, e.g. chemicals (12), electric equipment and machinery (18) and electronics (19). In these sectors there is little value and energy added, hence emissions embodied in exports are lower. Even if the emissions embodied in imported intermediates are taken into account (cf. figure 2), the total emissions embodied in the electronics (19) sector are still lower than the (domestic) emissions calculated in other models. The national and in this sector especially the regional model disregards therefore the high export processing share in the electronics sector - instead export production is assumed in relatively emission intensive provinces.

Compared to previous literature, our results for the emissions embodied in exports in the standard model are in line with other estimates. Several recent studies report emissions embodied in Chinese trade for 2007: Zhang (2012) and Yan and Yang (2010) report 1751 Mt and 1725 Mt, respectively. This is very close to our estimate of 1782 Mt.[6] Chen and

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[6] Wei et al. (2011) report 2814 Mt. The deviation might be due to their use of only 3 emission factors for solid, liquid and gaseous fuels. The share of emissions embodied in exports (34.8% of domestic emissions) is however relatively close to ours (32.3%).

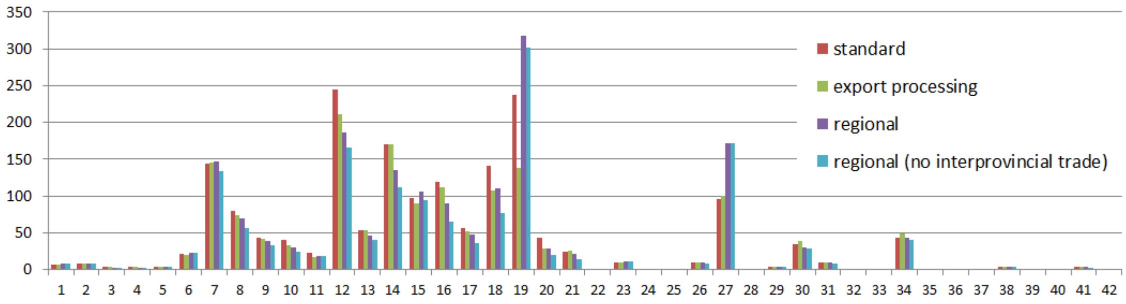

Figure 3: Domestic emissions embodied in exports by sector in different IO models (in Mt CO_2). Sector codes in Appendix A.5.

Zhang (2010) report 2021 Mt, their estimate includes also industrial process emissions, while the other studies (including ours) only report energy-related CO_2 emissions. Estimates of imported emissions vary much stronger depending on the assumption of Chinese or foreign technology.

When we compare the results from the regional model to estimates in the literature, we can provide a direct comparison with Su and Ang (2010) who compare a regionally disaggregated model with a national model. For the year 1997, they find that 16.4% of domestic emissions are embodied in exports, lower than the 19% estimated in a national model. Our drop in emissions embodied in exports when moving from the national to the regionally disaggregated model is smaller (32.3% to 31.9%). The overall increase in the percentage values compared to 1997 shows the growing importance of trade in China. The reduction in the difference between the estimates in the different models might be due to increased interprovincial trade (Feng et al., 2013), with a higher share of energy embodied in exports now originating from non-coastal provinces compared to 1997. Guo et al. (2012) find 688 Mt or 20.3% of domestic emissions embodied in exports for 2002.[7] The regionally disaggregated model of Feng et al. (2013) is closest to ours, but they focus more on domestic flows of embodied CO_2 and do not report emissions embodied in exports. Yet they confirm our finding that emissions originating in non-coastal provinces play a substantial role for the emissions embodied in export production.

For the model with special treatment of export processing, we provide an update to

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[7] Guo et al. (2012) use however a model that uses the domestic production assumption and then calculate emissions embodied in trade between provinces instead of a MRIO with TA^D. Their findings are therefore more comparable to the model without interprovincial trade.

studies using data for 1997 (Su et al., 2013) or 2002 (Dietzenbacher et al., 2012). Su et al. (2013) estimate 12.6% of domestic emissions embodied in exports (thereof 1.5 percentage points in export processing), lower than the 18.4% in a standard model. Dietzenbacher et al. (2012) also report 12.6% of domestic emissions embodied in exports (thereof 2.1 percentage points in export processing), lower than the 20.3% in a standard model. Our estimate of domestic emissions embodied in exports in the model with export processing is 28.6%, thereof 6.4 percentage points in export processing. These figures are higher and can be explained by the strong increase in trade volumes both inside and outside the export processing regime between 2002 and 2007 (see also Su et al., 2013).

6 Conclusions

We provide IO analysis of emissions embodied in Chinese exports. Relaxing the assumption of homogenous production in export and domestic sectors, we find that

- a standard model is likely to overestimate Chinese domestic emissions embodied in exports, because this does not take into account that a large share of exports is processing trade with little emissions added and that many exports are produced in provinces with lower than average emission intensity.
- for a regional model, interprovincial trade flows matter: They (partly) offset the lower emission intensity of export intensive provinces because export intensive provinces use energy intensive intermediates produced in more emission intensive provinces. This also shifts the regional distribution of emissions added to exports away from the coastal provinces.
- for a model with export processing, a larger share of emissions embodied in exports is from imported intermediates and domestically added intermediates are thus lower. This leads to lower domestic emissions embodied in exports.
- emissions embodied in imports are relatively low when emission intensities from a global MRIO model are used. The share of imported emissions that are re-exported

is different in the different IO models. While a standard and a regional model assume proportional use of imports in total use, the model with export processing takes into account that imports are used for export processing and a higher share of (energy intensive) imports is used for production of export goods.

The findings are policy relevant both on a macro and on a sectoral level. On the macro level, lower emissions embodied in exports (compared to standard estimates) translate into higher emissions of final use in China. This informs the discussion on the responsibility of Chinese emissions. On the sectoral level, emission embodied in certain sectors and therefore emission intensity of exports depend on the model chosen. This is crucial when considering policy effects of border carbon adjustments. When targeting international leakage concerns, it has to be taken into account that export processing might lead to much lower than average emission intensities.

Our results can also inform analysis on the current Chinese policy of introducing six pilot emission trading systems mostly in economically more advanced provinces and cities (National Development and Reform Commission, 2012). Both the regionally disaggregated model and the model with export processing provide valuable information on where emissions embodied in exports originate and thus how they might be affected by the policies. The regional disaggregation shows that the majority of emissions originates in coastal provinces, but a substantial share of emissions is embodied in exports initially comes from burning coal in non-coastal provinces. The model with export processing shows that emissions are mostly from non-processing exports. Export processing zones lie predominantly in the coastal areas, and are thus more likely to be included in an emission trading scheme. A binding emission trading systems in advanced regions will therefore not do much to curb emissions embodied in exports, despite the fact that many goods are exported from the pilot regions. Furthermore, the importance of interprovincial trade indicates that carbon leakage to non-regulated provinces could take place, offsetting part of the reduction efforts.

Rather than specifically reducing emissions of exports production and also given the high interprovincial trade we suggest a comprehensive approach for future Chinese policy. Such a broader approach could continue to strive for reduction of the share of coal in the energy mix or for an increase in R&D investment in energy saving and emission reducing technologies. As our results show, emissions embodied in exports are not specially a phenomenon of coastal regions. The Chinese government could thus also promote industrial transfer among regions to achieve emission intensity reductions in the non-coastal provinces. This would also take into account equity considerations between regions and act as a means to realize balanced development. The planned future expansion of the regional coverage of the emission trading schemes can be an adequate policy to reduce emissions at low costs prevent leakage between provinces.

Our main aim in this study is to identify differences between more complex IO models compared to a standard model for China. While our results are of relevance both at the aggregate as well as the disaggregated level, future work could lead to an even better understanding of the observed results. A decomposition analysis of changes between years would be fruitful for understanding the drivers of emission growth and provide better targeted policy recommendations, especially as the differences in the regionally disaggregated models and in the model with export processing are relative large compared to the existing literature estimates for 2002.

Further limitations of the study rest in the uncertainty of the underlying data, e.g. inconsistencies between the national and the regional IO tables or energy data (see also Guan et al., 2012). This requires balancing the IO tables to match the national values and potentially adds noise to the data. In this study we can also only compare the results of the regional and the export processing model. Since export processing is however concentrated in provinces with lower emission intensity, it can be expected that taking into account both features in the same model would influence our model results. A model taking into account both features is however beyond the scope of this paper.

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A Appendix

A.1 Standard (national) input output model

For the standard estimation we use the 2007 IO table for China (National Bureau of Statistics of China, 2009b), and energy information provided by the energy yearbook (National Bureau of Statistics of China, 2009a). Since energy use is grouped only into 7 sectors, the energy use is split according to the share of corresponding intermediate energy inputs in the various sub-sectors.

The calculation of A^D is made using a proportional assumption which implies the use ratio of domestic and imported goods is equal for intermediate and final use: $A^D = SA$. The elements of the diagonal matrix S contain the sectoral import shares $s_i = m_i/(x_i + m_i - e_i)$, calculated as the share of imports m_i over total demand less exports e_i. This assumes that imports are used in same proportion in each sector and final demand (Weber et al., 2008).

We follow Guan et al. (2012) in the calculation of emissions (excluding process emissions) and estimate national emissions to be 5513 Mt CO_2. Emissions are very similar to Guan et al. (2012), but lower than most studies conducted with the 2007 IO table reviewed in Su and Ang (2013). A difference is that the energy data is taken from a different source. The reason is that the energy source needs to allow for disaggregation on the spatial level, i.e. energy information for the province level needs to be compatible with the source used for the national IO analysis. Energy use is attributed to the different sectors proportionally according to the energy value input share of the respective sector in the IO table.

For the calculation of emission intensity of imports F^M we employ a global MRIO model based on the GTAP 8 dataset which provides CO_2 emissions and input-output data for 129 regions and 57 sectors for the year 2007 (Narayanan et al., 2012). The 57 sectors are mapped to the the 42 sectors of the Chinese IO table. The calculation of the i^{th} element of F^M is a weighted sum of emission intensities of China's imports in sector i from all trade partners. We use this average sectoral numbers since we do not have information of how imports in the same sector from different countries are used in China. This yields lower emission intensities for imports compared to Chinese production intensities F.

A.2 Spatial disaggregation

For the spatially disaggregated input output models, we augment the data from the IO table with additional information taken from provincial IO tables (National Bureau of Statistics of China, 2011), provincial energy flow data (National Bureau of Statistics of China, 2009a) and information on interprovincial trade.

The regional IO tables are scaled and re-balanced to match the national table by applying the cross-entropy method:

$$min \sum_{r,i,j} x_{r,i,j} ln \frac{x_{r,i,j}}{x^0_{r,i,j}} + \sum_{r,i} va_{r,i} ln \frac{va_{r,i}}{va^0_{r,i}} + \sum_{r,i} y_{r,i} ln \frac{y_{r,i}}{y^0_{r,i}}$$

$$s.t. \sum_r x_{r,i,j} = \overline{x_{i,j}}$$

$$\sum_r va_{r,i} = \overline{va_i}$$

$$\sum_r y_{r,j} = \overline{y_j}$$

$$\sum_i x_{r,i,j} + va_{r,j} = y_{r,j}$$

Intermediate inputs $x_{r,i,j}$, value added $va_{r,i}$, and output $y_{r,i}$ in each sector are matched to the respecting national total (marked with bar). Values marked ^{0} indicate initial values taken from the regional IO tables.

Energy use taken from regional energy balance tables is also adjusted to sum up to the national values. Initial calibration is based on the adjustment for regional IO coefficients. For example, if the intermediate input of coal in one sector was reduced by 20%, the initial value for coal use in that sector is the value taken from the energy data reduced by 20%.

We also balance regional imports from abroad to match national imports by applying cross-entropy method:

$$min \sum_{i,r} m_{i,r} ln \frac{m_{i,r}}{m^0_{i,r}}$$

$$s.t. \sum_r m_{i,r} = \overline{m_i}$$

$$\sum_i m_{i,r} = \overline{m_r}$$

The values for sectoral imports $\overline{m_i}$ are taken from the national IO table, the value for regional imports $\overline{m_r}$ are taken from National Bureau of Statistics of China (2009b, Table 17-12). Since the two values are different, we scale the regional imports such that $\sum_r \overline{m_r} = \overline{M}$ holds. The initial values of $m^0_{i,r}$ are based on total inflows into a province (including domestic inflows from other provinces), scaled such that they sum up to the total imports.

Provincial imports $m_{i,r}$ are bound upwards by the minimum of total use and total inflows into a province. For sectors where this renders the problem infeasible, only total use is used as an upper bound.

Entropy estimation of the interregional trade flow matrix T is based on regional inflow and outflow data from IO tables and gravity estimation using freight data from railway transport for average transport between 2006 and 2008 (China Transportation & Communications Press, 2009). The average 2006-2008 is used to avoid outliers. Independent variables in the gravity estimations used to predict trade flows are the log of distance between the provincial capitals of the trade pair, the log of GDP of the importing and exporting province, and dummies to indicate whether the trade flows are between neighbor provinces or whether municipalities (Beijing, Tianjin, Shanghai, Chongqing) are either the importer or exporter. The predicted trade flows are scaled to match the trade flow in a given sector and used as initial value in the estimation of trade matrix T for the initial calibration.

Trade flows are calculated sectorwise, such that trade flows $t_{r,s}$ from region r to s match inflows a_s and outflows b_r in a given province.[8] a and b are taken from the regional IO tables. Imports to abroad and exports from abroad are deducted from the flows and the values are scaled so that total inflows equal total outflows.

$$min \sum_{r,s} t_{r,s} ln \frac{t_{r,s}}{t^0_{r,s}}$$

$$s.t. \sum_{r} t_{r,s} = a_s$$

$$\sum_{s} t_{r,s} = b_r$$

The interprovincial trade matrix T is than calculated by dividing trade flows $t_{r,s}$ by total use of the destination province. The main diagonal of T is set such that the column sums equal one.

A.3 Disaggregation of export processing sector

For the IO model with a disaggregated export sector, we use customs data for export processing trade (taken from Koopman et al., 2008). The data provides information on the share of exports in a sector produced under the export processing regime. Furthermore, the shares for specific use of imports (intermediate input in either the normal domestic or

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[8] We drop the sectoral subscript i as the optimization problem is solved for each sector independently.

the export processing sector, or in other categories of final demand) are reported. These shares are used to split sectoral imports of the national IO table into imports for final use, imports for use as intermediates in the normal sector m_i^N and the export processing sector m_i^P. We split exports and final demand accordingly.

The initial values of Z^0 are calculated by first attributing the intermediate inputs of the national table $\overline{Z}$ into a normal and export processing sector based on the shares of in total output. Denoting the set of sector types N, P with τ and the set of the origin of inputs D, M by σ, we have

$$z_{i,j}^{P*} = \overline{z_{i,j}} \frac{e_j^P}{x_j}$$

$$z_{i,j}^{N*} = \overline{z_{i,j}} \frac{x_j - e_j^P}{x_j}$$

$$z_{i,j}^{M,\tau^0} = m_i^\tau \frac{Z_{i,j}^{\tau *}}{\sum_j z_{i,j}^{\tau *}}$$

$$z_{i,j}^D = \overline{z_{i,j}} - \sum_\tau z_{i,j}^{M,\tau^0}$$

$$z_{i,j}^{D,P^0} = z_{i,j}^D \frac{e_{p,j}}{x_j}$$

$$z_{i,j}^{D,N^0} = z_{i,j}^D \frac{x_j - e_j^P}{x_j}$$

We then re-balance the elements the disaggregated IO table, such that its values match their equivalents from national input output table:

$$min \sum_{\sigma,\tau,i,j} z_{i,j}^{\sigma,\tau} ln \frac{z_{i,j}^{\sigma,\tau}}{z_{i,j}^{\sigma,\tau 0}} + \sum_{\tau,j} va_j^\tau ln \frac{va_j^\tau}{va_j^{\tau 0}}$$

$$s.t. \sum_{\tau,j}^{\tau} z_{i,j}^{D,\tau} + e_i^N + y_i^D = x_i - e_i^P$$

$$\sum_{\tau,j} z_{i,j}^{M,\tau} = m_i^\tau$$

$$\sum_{\sigma,i} z_{i,j}^{\sigma,N} + va_j^N = x_j - e_j^P$$

$$\sum_{\sigma,i} z_{i,j}^{\sigma,P} + va_j^P = e_j^P$$

$$\sum_{\sigma,\tau} z_{i,j}^{\sigma,\tau} = \overline{z_{i,j}}$$

$$\sum_{\tau} va_i^\tau = \overline{va_i}$$

The coefficients matrices A^{NN}, A^{NP}, A^{MN}, and A^{MP} are then obtained by dividing the respective Z matrices by output of N or P, respectively.

A.4 Provinces of China

1 Beijing	11 Zhejiang	21 Hainan
2 Tianjin	12 Anhui	22 Chongqing
3 Hebei	13 Fujian	23 Sichuan
4 Shanxi	14 Jiangxi	24 Guizhou
5 Inner Mongolia	15 Shandong	25 Yunnan
6 Liaoning	16 Henan	26 Shaanxi
7 Jilin	17 Hubei	27 Gansu
8 Heilongjiang	18 Hunan	28 Qinghai
9 Shanghai	19 Guangdong	29 Ningxia
10 Jiangsu	20 Guangxi	30 Xinjiang

Table 2: Provinces of mainland China. Tibet is not included due to a lack of data.

A.5 Sectors

1 Agriculture, Forestry, Animal Husbandry & Fishery
2 Mining and Washing of Coal
3 Extraction of Petroleum and Natural Gas
4 Mining of Metal Ores
5 Mining and Processing of Nonmetal Ores and Other Ores
6 Manufacture of Foods and Tobacco
7 Manufacture of Textiles
8 Manufacture of Textile Wearing Apparel, Footwear, Caps, Leather, Fur, Feather (Down) and its products
9 Processing of Timbers and Manufacture of Furniture
10 Papermaking, Printing and Manufacture of Articles for Culture, Education and Sports Activities
11 Processing of Petroleum, Coking, Processing of Nuclear Fuel
12 Chemical Industry
13 Manufacture of Nonmetallic Mineral Products
14 Smelting and Rolling of Metals
15 Manufacture of Metal Products
16 Manufacture of General Purpose and Special Purpose Machinery
17 Manufacture of Transport Equipment
18 Manufacture of Electrical Machinery and Equipment
19 Manufacture of Communication Equipment, Computer and other Electronic Equipment
20 Manufacture of Measuring Instrument and Machinery for Cultural Activity & Office Work
21 Manufacture of Artwork, Other Manufacture
22 Scrap and Waste
23 Production and Supply of Electric Power and Heat Power
24 Production and Distribution of Gas
25 Production and Distribution of Water
26 Construction
27 Traffic, Transport and Storage
28 Post
29 Information Transmission, Computer Services and Software
30 Wholesale and Trade
31 Hotels and Catering Services
32 Financial Intermediation
33 Real Estate
34 Leasing and Business Services
35 Research and Experimental Development
36 Comprehensive Technical Services
37 Management of Water Conservancy, Environment and Public Facilities
38 Services to Households and Other Services
39 Education
40 Health, Social Security and Social Welfare
41 Culture, Sports and Entertainment
42 Public Management and Social Organization

Table 3: Sectors in the Chinese IO table.