Regional differences in carbon content in processing exports and non-processing of China

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Abstract: *(minimum 300 words)*

The different regions of the world have been specialized in different phases of production. Developed countries have specialized more in the production of services while some regions of developing countries in the production of goods that mainly require low-skilled labor and can be produced at a lower cost (Meng et al., 2017; Tian et al., 2014). Therefore, developed countries are usually net importers of embodied carbon emissions, whereas developing countries, such as China, are net exporters (Davis and Caldeira, 2010). Although, exist a significant differences in European Union regional contribution in terms of total and per capita emissions suggest large spatial inequalities of climate change responsibility (Ivanova et al., 2017). In this context, the input-output framework and, specifically, the environmental extended Multiregional Input-Output Model (MRIO), allows us to adequately address the importance of global production chains, where the distinction between normal and processing exports is critical, as well as their impact on the environment.

China's processing exports account for more than half of its total exports. In addition, processing trade is concentrated on a few products and is different from non-processing trade. For instance, over 65% of processing trade falls into the category of "Machinery and transport equipment", which requires more technology than others industries (Kim, 2017). At the same time, carbon embodied in processing exports in China is significantly lower than carbon embodied in non-processing exports, because they have less connection with domestic industries, more intensely polluting (Dietzenbacher et al., 2012). It is reflecting the structural change that is taking place in China in recent years

increasingly adding value to imports rather than simply processing raw materials. In this context, we wonder about the consequences of these changes in terms of emissions embodied in trade and the differences in the emissions associated with both types of trade and how those differences are explained. For it, in this paper we propose a Structural Path Analysis (SPA) to analyze China's processing exports and the related emissions and the differences with non-processing exports using the ICIO tables for 2011. SPA is used to identify the contribution each part of the value chain, identifying key flows and industries, differences between domestic and imported and the embodied emissions effects of imported inputs into Chinese exports.

Keywords: *Multiregional Input-Output Model, Structural Path Analysis, Global value chains, processing exports, emissions embodied in trade.*

JEL codes: C67, F18, F62, F64, Q56

1. Introduction

China is currently the world's top emitter, producing around 30% of global GHG emissions (IPCC, 2014; Shan et al., 2018). Declining emissions between 2014 and 2016 led some researchers to postulate that the peak may have been reached, due mainly the decrease of coal use in China (Jackson et al., 2015). However, coal use increased in 2017 for the first time in three years (although it remained below its 2013 peak), which, together with rising demand for oil and gas, drove CO_2 emissions above 2014 levels, the previous record high (Climate Action Tracker, 2018).

CO_2 emissions embodied in international trade account for 26.4% of global emissions in 2007 and China with a 23.3% of this total was the main emissions exporter to the rest of the world (Arce et al., 2016). In the period 1995-2008, important CO_2 clusters in China are induced by global supply-chain networks associated with U.S. transport equipment and construction demand (Kagawa et al., 2015). More recently some authors find that domestic Chinese export-embodied CO_2 emissions peaked in 2008 and later emissions embodied in China's exports trended downward during 2008–2015 (Mi et al., 2018).

The analysis of the role of processing trade in China is attracting attention in the literature from different points of view, such as in terms of productivity (Kim, 2017), generation of added value, attraction of FDI (Zhang, 2015) and also in terms of impact in CO_2 emissions (Dietzenbacher et al., 2012), energy requirements (Zhang et al., 2017a). In terms of CO_2 emissions, although more than one half of Chinese exports are related to international fragmentation of production, carbon embodied in processing exports in China is significantly lower than carbon embodied in non-processing exports, because they have less connection with domestic industries, more intensely polluting (Dietzenbacher et al., 2012). In this context, we wonder about the consequences of these changes in terms of emissions embodied in trade and the differences in the emissions associated with both types, since the higher importance of normal Chinese exports could lead to an increase in emissions embodied in exports if this trade is not compensated by mitigation policies.

However, a structural change that is taking place in China in recent years increasingly, adding value to imports rather than simply processing raw materials (Kim, 2017), while investments based on low-wage benefits are shifting to other regions of the world more

competitive than China nowadays (Arce et al., 2016) and part of the Chinese imports, particularly in raw materials and intermediate goods production in energy-intensive sectors, are moving to other developing countries (Meng et al., 2018). China's trade diversion that can lead to emissions savings, as the pollution haven hypothesis literature has shown, especially when it is replaced by countries that are intensive in natural resources ((Zhang et al., 2017b) (López et al., 2018)) with an energy mix less intensive in CO_2 emissions (Arce et al., 2016).

In addition, processing trade is concentrated on a few products and is different from non-processing trade. For instance, over 65% of processing trade falls into the category of “Machinery and transport equipment”, which requires more technology than others industries (Kim, 2017). The fact that the direct emissions embodied in Chinese exports are less important than the indirect emissions related to the rest of the sectors that supply inputs ((López et al., 2014), (Skelton, 2013) (Zhang et al., 2017a)) shows the need to identify the key sectors (domestic and imported) for monitoring the linkages that dominate CO_2 emissions in global supply chains.

In this context, the input-output framework and, specifically, the environmental extended Multiregional Input-Output Model (MRIO), allows us to adequately address the importance of global production chains, where the distinction between normal and processing exports is critical, as well as their impact on the environment. For it, in this paper we propose a Structural Path Analysis (SPA) to analyze China's processing exports and the related emissions and the differences with non-processing exports using the ICIO tables. SPA is used to identify the contribution each part of the value chain, identifying key flows and industries, differences between domestic and imported and the embodied emissions effects of imported inputs into Chinese exports.

2. Materials & Methods

The environmental extended Multiregional Input-Output Model (MRIO) is the most used method in the literature nowadays to estimate pollution and evaluate the role of international trade on the environment in terms of emissions, water, land use, etc. The MRIO allows us to adequately address the importance of global production chains,

where the distinction between normal and processing exports is critical, as well as their impact on the environment.

The fundamental equation of the environmental extension of the MRIO model (Atkinson et al., 2011; Davis and Caldeira, 2010) provides the environmental impact of production processes ($\boldsymbol{E}$), in our case, CO_2-eq emissions, as in expression [1]:

$$\boldsymbol{E} = \hat{\boldsymbol{e}}\,(\boldsymbol{I}-\boldsymbol{A})^{-1}\hat{\boldsymbol{y}} = \hat{\boldsymbol{e}}\boldsymbol{L}\hat{\boldsymbol{y}} \qquad [1]$$

where $\hat{\boldsymbol{e}}$ refers to the direct emissions coefficients or the diagonalized vector of emissions per unit of output. $\boldsymbol{A}$ is the integrated matrix of technical coefficients, integrated by $\boldsymbol{A}^{rr}$ in the main diagonal, which is the domestic matrix of coefficients of production (intraregional matrix), and $\boldsymbol{A}^{rs}$ in the off-diagonal positions, which indicates the trade between industries from region r to region s (intermediate exports of region r or intermediate imports of region s). The term $\boldsymbol{L}$ is the Leontief inverse represents the total requirements matrix that, multiplied by the intensity factor (in our case $\hat{\boldsymbol{e}}$) indicates the amount of emissions per unit of output destined to satisfy a unit of final demand, designated as emission multiplier or total emissions intensity. Finally, $\hat{\boldsymbol{y}}$ is the matrix (or the diagonalized vector) of final demand. Multiplying the emission multiplier by the matrix of final demand we obtain the total emissions (direct and indirect) ($\boldsymbol{E}$) to meet the final demand.

An advantage of the Leontief model is the ability to observe how final demand iniciate production processes and trace chains of intermediate consumption through layers or tiers. We can approximate each one of the layers decomposing the Leontief inverse in

different production phases, using the Taylor series approximation (Jing et al., 2015; Skelton et al., 2011; Zhang et al., 2017a) as shown in Eq [2].

$$L = (I - A)^{-1} = I + A + A^2 + A^3 + \cdots + A^t \text{ where } t \to \infty \qquad [2]$$

Each element of the expansion in Eq [2] denotes a different production layer and represents the production of intermediate goods used as input into the preceding layer.

In practice, it is impossible evaluate the infinite number of layers. However, the number of nodes decreases with path length. Therefore, in this first stage of the work we have focused the study on the first three layers and the total emissions:

$$E_0 = \hat{e} I \hat{y}$$
$$E_1 = \hat{e} A \hat{y}$$
$$E_2 = \hat{e} A^2 \hat{y} = \hat{e} A A \hat{y}$$

In this paper we use the OECD Inter-Country Input-Output (ICIO) Tables (OECD, 2016) based on ISIC Revision 3 (available in **oe.cd/icio)**. The choice of this database is motivated by the possibility of studying the processing trade for a country where this type of trade has been prevalent. Specifically, OECD-ICIO tables distinguish 62 economies (included RoW) and 34 sectors, but for intermediate use, this tables distinguish three production types for China and two productions types for Mexico. Regarding CO_2 emissions, we mainly rely on IEA's statistics on CO_2 emissions from fuel combustion (IEA, 2015) and reconcile them into the classification of OECD-ICIO table. Then, we have estimated the emissions by processing and non-processing exports for China following the method of Jiang et al. (2016) and Jiang et al. (2018).

Therefore, applying the SPA we can identify the contribution each part of the value chain and the key flows and industries, differences between domestic and imported and the embodied emissions effects of imported inputs into Chinese exports.

The database used shows very different patterns of consumption and investment, so the final demand has been aggregated into two categories: consumption and investment. Then we can differentiate the first three layers of emissions induced by consumptions and represent the first three layers of emissions induced by investment.

3. Main results

3.1. China's trade in normal goods, processing exports and non-processing exports

In recent years, the share of processing trade in total is decreasing in favor of the ordinary trade (Kim, 2017). In 2011, it represented 4% of the total Chinese output and 22.5% of goods exporters. The highest percentage of Chinese exports is referred to the non-manufactured processes, including primary sector, extraction, energy and services, followed by Chinese non-processing goods exporters and, finally, processing exports (Figure. 1).

Figure 1. Chinese output by production type, percentages.

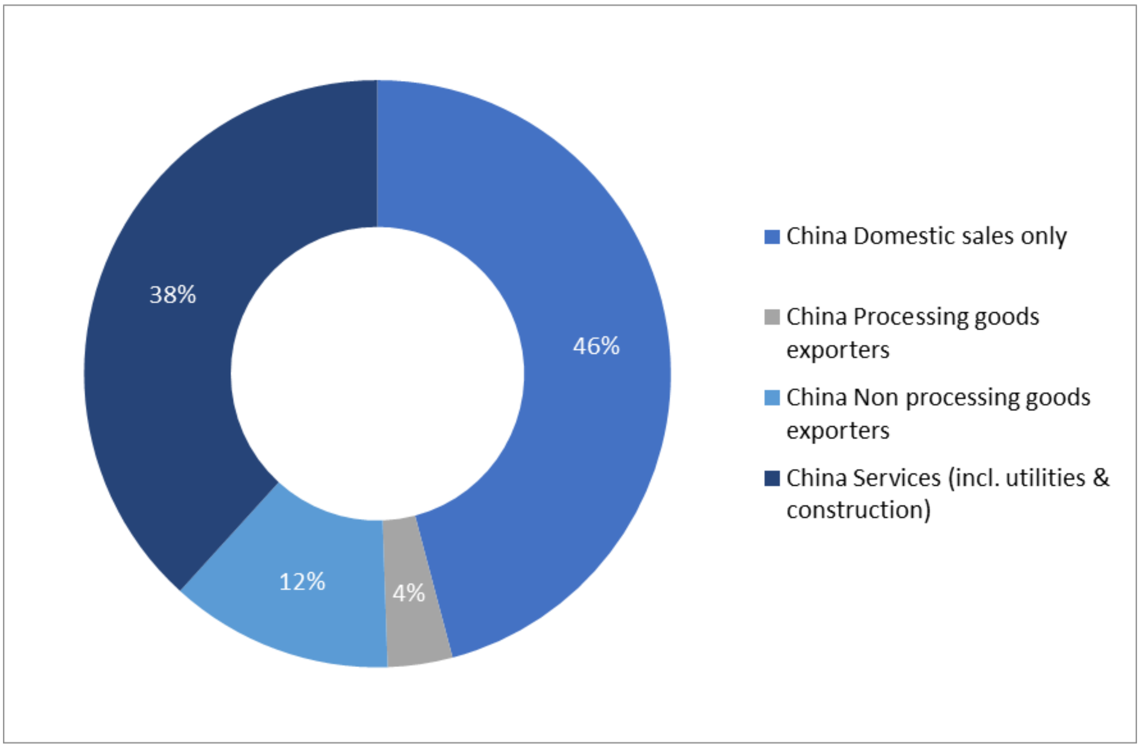
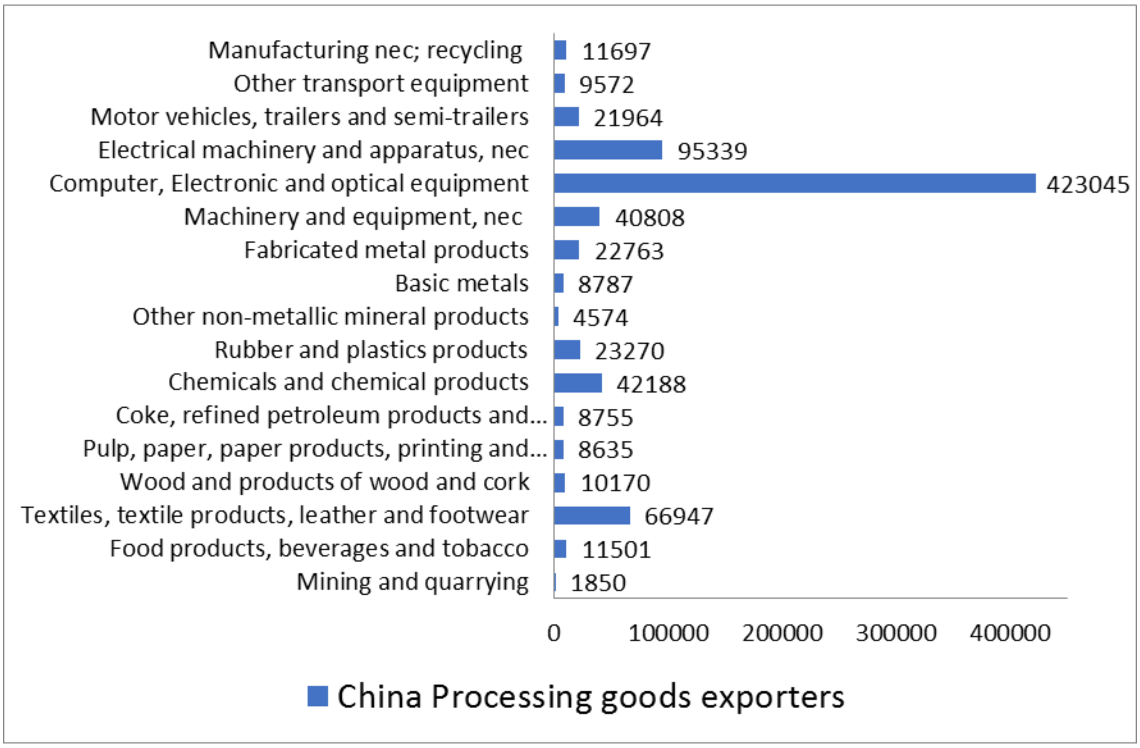


Figure 2 shows that processing trade is highly concentrated on specific sectors, highlighting Computer, Electronic and optical equipment, Electrical machinery and apparatus and the textile sector. These three industries represent 72% of the processing trade in China in 2011.

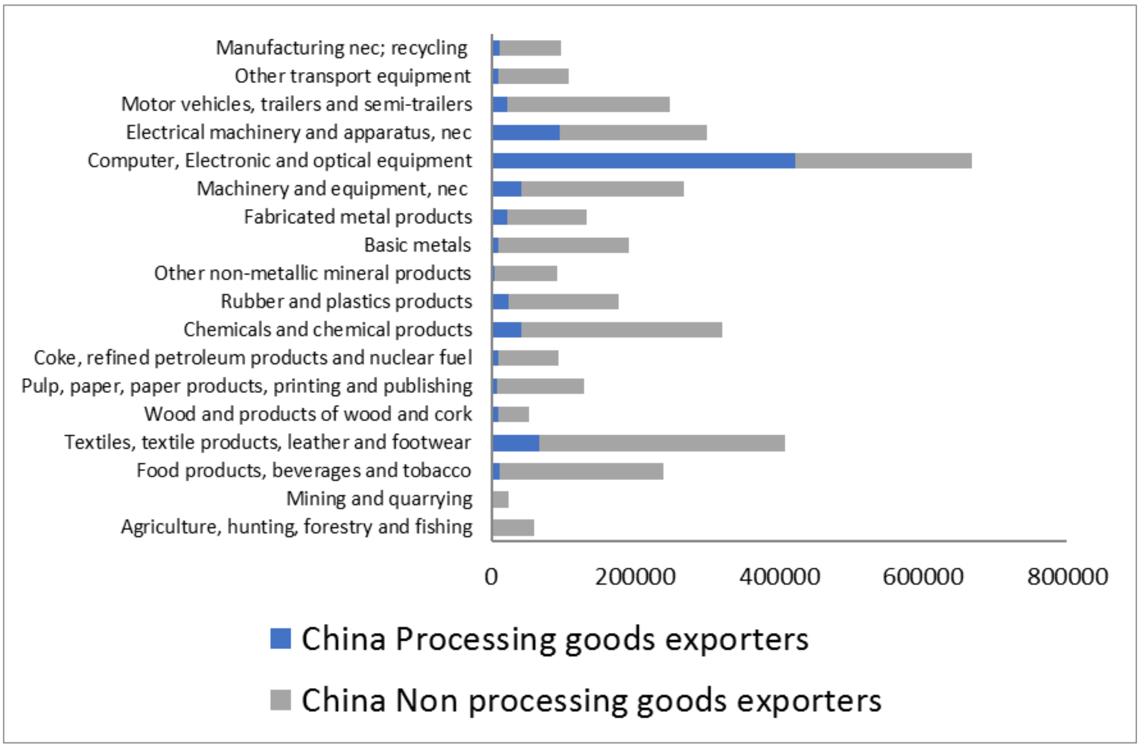
Figure 2. Processing exports by industries.



Especially noteworthy is the case of Computer, Electronic and optical equipment, where the top export products are mobile phones followed by computers then integrated electronic circuits (General Administration of Customs of the People's Republic of China, 2017), This positioning as the largest high-tech exporting country is mainly due to the relocation of production capacities by multinational enterprises into China (Xing, 2017), which are the ones that conduct most of the processing trade, about 80% of processing trade in 2014 (Kim, 2017). In this industry, processing exports represent 63% of the total (Figure 3).

Other significant sectors are Textiles (where 16% is processing trade), Chemicals products (13%), Electrical machinery and apparatus (32%) and Machinery and equipment (15%). In addition, there are other industries that are not so relevant in terms of export volume but have an important share of processing exports, such as Wood and products of wood and cork (19%), Fabricated metal products (17%) or Rubber and plastics products (13%) (Figure 3).

Figure 3. Composition of processing and non-processing exports, 2011



3.2. Carbon emissions in trade.

Total emissions, embodied in both consumer goods and investment, that have more importance on the total are, first, those related to the domestic economy (services and energy), followed by total emissions embodied in non-processing exports and, finally those embodied in processing exports (Table 1). However, in relative terms, the activities related to processing exports transfer their emissions to the rest of the world almost entirely (91% in investment and 97% in consumption). Emissions embodied in non-processing exports are transferred 49% for consumption and 30% for investment to other countries. Finally, the emissions share that the Chinese domestic economy exports is only 15% for consumption and 6% for investment.

Table 1, Carbon emissions related to consumption and investment of the first six layers (from 0 to 5) of China and RoW, 2011 (Mt CO_2)

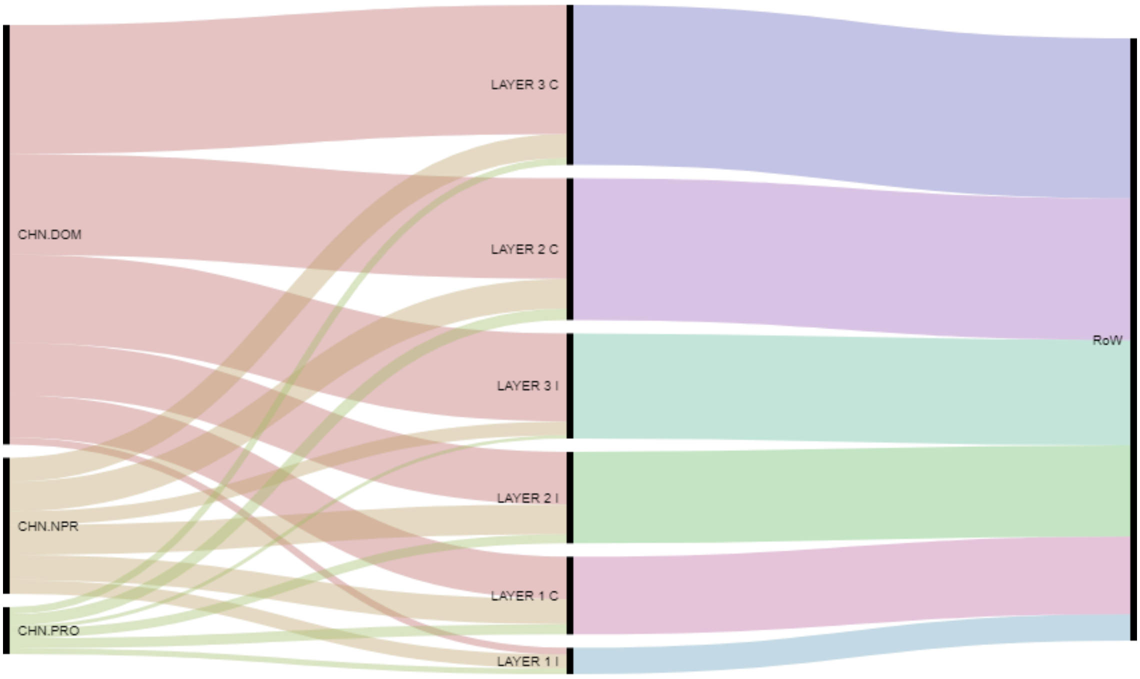
Total Layer C	Total	CHINA.Total	RoW	Exports/Total
CHN.DOM	2555.35	2030.15	525.21	21%
CHN.PRO	32.30	0.99	31.32	97%
CHN.NPR	203.92	104.69	99.23	49%
RoW	16529.27	172.27	16357.00	1%
Total	19320.85	2308.10	17012.75	
%CHINA/Total		12%		

Total Layer I	Total	CHINA.Total	RoW	Exports/Total
CHN.DOM	3534.00	3217.94	316.06	9%
CHN.PRO	20.85	1.77	19.07	91%
CHN.NPR	237.28	170.76	66.52	28%
RoW	4888.29	227.09	4661.20	5%
Total	8680.43	3617.57	5062.85	
%CHINA/Total		42%		

Total Layer C+I	Total	CHINA.Total	RoW	Exports/Total
CHN.DOM	6089.35	5248.09	841.27	14%
CHN.PRO	53.15	2.76	50.39	95%
CHN.NPR	441.20	275.45	165.75	38%
RoW	21417.57	399.37	21018.20	2%
Total	28001.27	5925.67	22075.60	
%CHINA/Total		21%		

Regarding CO_2 emissions in the first three layers, highlights the fact that layer one is lower than the second and third both for consumption and capital goods (Figure 4). For instance, for consumer goods, the first layer is 37 MtCO_2, the second is 88 MtCO_2 and the third is 113 MtCO_2, which shows that more emissions-intensive inputs are being involved in the successive stages of the production process. This indicates that, in terms of emissions, linkage effects are more important than direct emissions. In terms of volume, emissions embodied in exports of consumer goods are more important than those from investment goods, as the volume of consumer goods exported is higher than investment goods, although consumer goods are less carbon-intensive than investment.

Figure 4. Importance of the first three layers in emissions embodied in Chinese exports for domestic economy (energy, construction and services), no processing exports and processing exports, 2011 ($MtCO_2$).



3.3 Sectores oferentes e impulsores del carbono en exportaciones

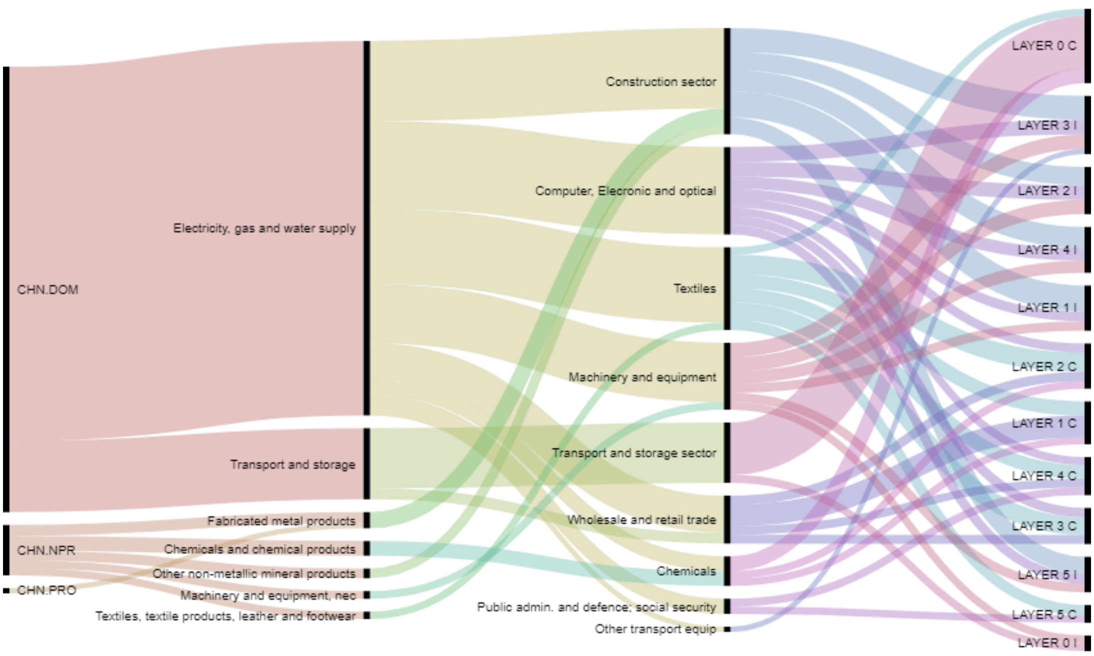
The first 40 paths of consumption (20 paths) and investment (20 paths) represent 40% of the total emissions embodied in China's trade with the RoW, showing a high concentration (only 40 flows on a total 20,808 sectoral relationships incorporated in the first 3 layers). The carbon supply industries are mainly two sectors than are in the region de China domestic o non-manufacturing products: Electricity (40%) and, Transport and storage (around 20%). Then, with lower weight, are found the industrial sectors which produce both processing and non-processing goods: metals, other non-metals, machinery and textiles. These sectors present high emissions coefficients and important presence in exports. The exception is the Electricity sector, which is not exported, therefore emissions from this sector have no presence in the first layer, but rather is a significant supplier of the rest of the industries.

Regarding sectors that boost exports, their importance is more distributed than the sectors that supply emissions. Specifically, we find 9 industries with significant weight, although in decreasing order (Figure 5). First, we have to highlight the construction

sector, followed by the sectors responsible for producing the final and intermediate exported goods: computers, textiles, machinery and chemistry products, etc. On the other hand, the service sectors, necessary for exports, such as transport and distribution. In conclusion, the reading on the left and right of the Figure 5 allow us to conclude that que there is no coincidence between the sectors that generate CO_2 emissions and the sectors that drive or boost exports. The most important exception is the transport and storage sector, which is very carbon intensive and is also essential for transferring goods from China to the rest of the world (basic trade sector).

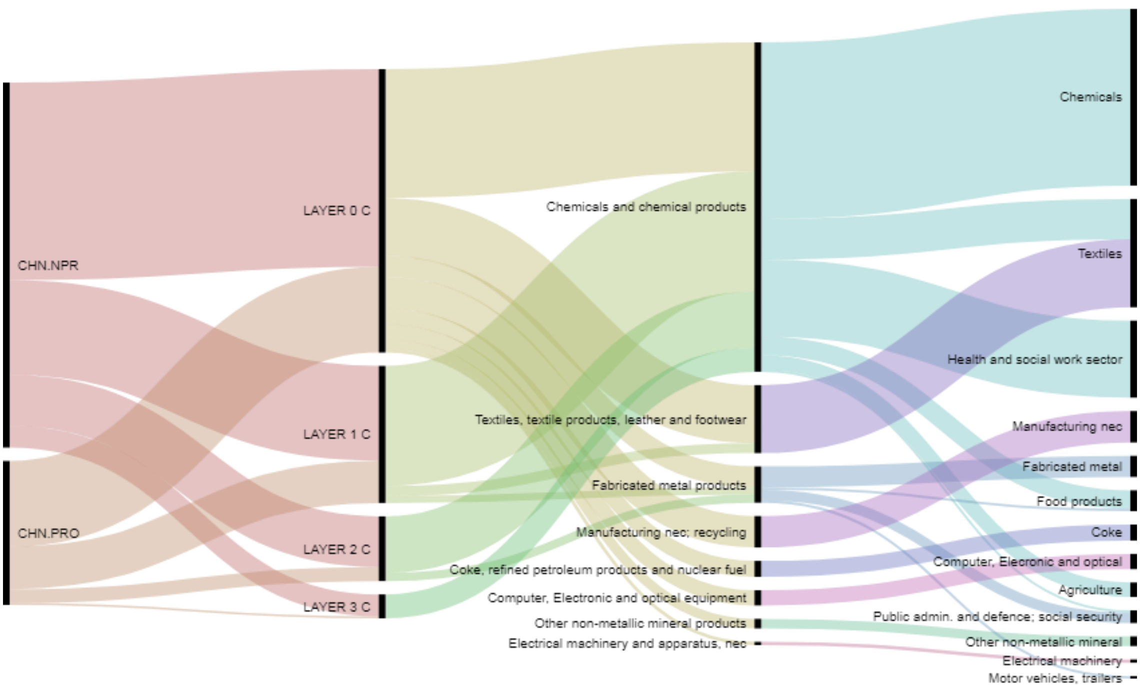
In relation to the final demand components, consumer and investment goods and commodities, that boost emissions, a different pattern has been detected between both types of goods. In consumer goods, carbon emissions embodied in the first layer are the most important and in the following layers emissions are gradually reduced. However, for investment goods the first layer incorporates a reduced emissions volume, which increases significantly for the second and even the third layer and start to decrease in the following layers. This difference between consumer and investment goods shows that, while direct emissions are more important in consumer goods, indirect emissions are more important in the production of investment goods.

Figure 5. Carbon emissions embodied in the 40 first paths of consumption and investment by origin and destination sector for China domestic, processing and non-processing, 2011



Focus on the consumer goods of processing and non-processing exports, we observe the existence of industrial conglomerates through emissions are shifted between suppliers and demanders of inputs (Figure 6). Therefore, for consumer goods, is worth noting the basic character of the chemical sector, which is the largest emissions supplier for industrial goods and also supplies a large number of exporters sectors: the chemical industry itself on layer 0 (initial), and to sectors such as textiles, agriculture, health and food in the successive layers. Something similar happens with the Manufacture of metallic products, which transfers emissions to the own sector and then, to the AAPP and defense and the production of motor vehicles. On the other hand, sectors such as textiles, coke and refining or computers are highly integrated and emissions are transferred between the companies in the own sector and are transferred in a small amount to the rest of the manufacturing industries.

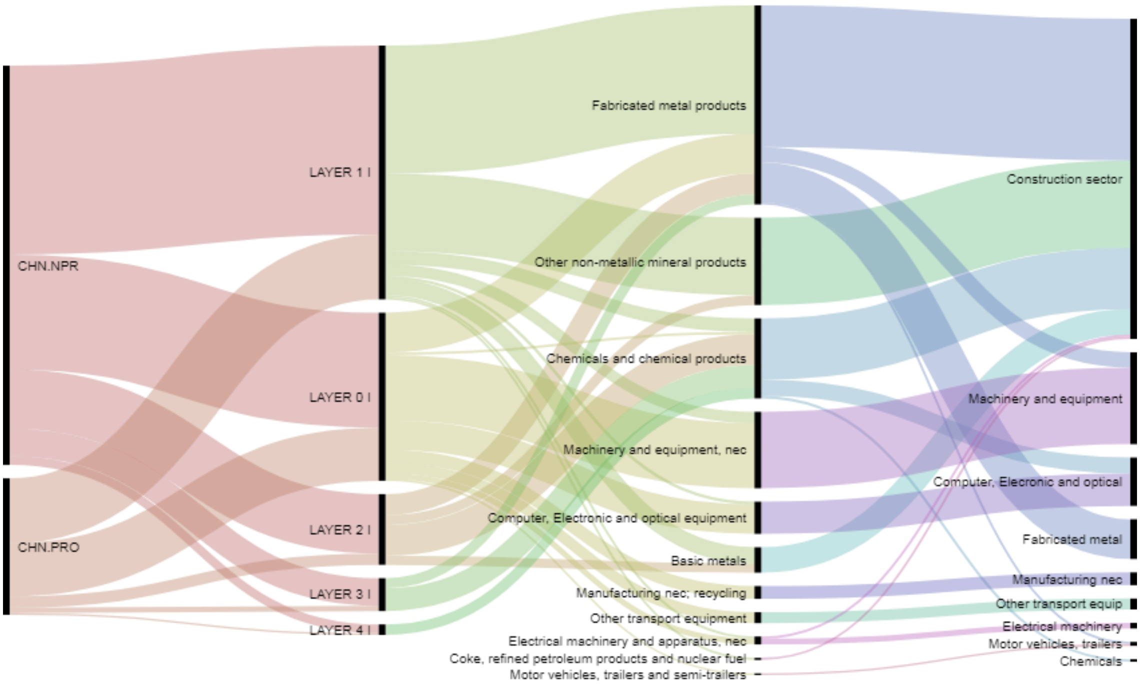
Figure 6. Carbon emissions embodied in the 40 first paths of consumer goods by origin and destination sector fon procesing and non-processing exports, 2011



Analyzing carbon emissions embodied in investment goods of processing and non-processing (Figure 7) are important, as in consumer goods, sectors of metal fabrication and chemicals as sectors that supply an important amount of emissions to other industries. The main difference observed appears on the side of the boost emissions sectors. The construction sector appears, as a sector that generate, as a consumer, 60%

of the total emissions (from Manufacture of metals, non-metallic minerals and chemical sector), which results consistent with the important cluster of emissions found among US trade and China by Kagawa et al. (2015).

Figure 7. Carbon emissions embodied in the 40 first paths of investment goods by origin and destination sector fon procesing and non-processing exports, 2011



Conclusions

The application of structural path analisys method on exports of Chinese products, differentiating between normal goods, processing exports and non-processing exports, has allowed us to identify the key sectors in the transmission of carbon, either as emissions suppliers or as boost of exports to the rest of the world.

Regarding sectors that supply emissions embodied in exports, are very concentrated in the productive activities of the Chinese domestic economy (primary sector, energy and services), highlighting Electricity (with more than 50%) and followed by transport and storage. Sectors that are responsible for direct CO_2 emissions in the economy. However, in the manufacturing sector, both for processing and non-processing exports, the embodied emissions are lower, highlighting the metal, mineral and chemical manufacturing industries, which are energy intensive and necessary for the manufacture of products.

Regarding key sectors as boost of emissions, are mostly industrial sectors, transport services and construction. The non-coincidence between suppliers and boost sectors leads us to recommend the joint adoption of production-based and consumption-based mitigation policies. These last ones (ecolabeling or border taxes) would transmit information and responsibility to consumers of Chinese products from the rest of the world and from there, the possibility of integrating the "sustainability factor" into their consumption decisions.

About the importance of the sectors boost, differenciating consumer and investment goods, it has been verified that direct emissions are more important in consumer goods and indirect emissions are more important in the production of investment goods. In this sense, when transferring technology between companies from different countries that trade with Chinese companies or those companies that are located there, it should be considered which type are. If they are companies that produce consumer goods, it would be necessary to encourage an emissions transfer that reduces both direct emissions and those related to the use of intermediate goods. However, for firms producers of investment goods, the attention must be focused on the technology used by the suppliers of these companies, rather than on production techniques, direct emissions or direct fuel use for instance.

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Tabla asociada a Figura z.2 (S.I.9. Emisiones de CO2 en los 40 primeros layers de consumo y de inversión por sectores de origen y de destino, 2011

ORIGEN SECTOR	Layer	Destino sector	Valor Exportado Row	% Exportaciones
Transport and storage	LAYER 1 C	Transport and storage sector	31.2	5.9%
Electricity, gas and water supply	LAYER 3 C	Textiles	11.5	2.2%
Electricity, gas and water supply	LAYER 3 I	Construction sector	10.9	2.1%
Chemicals and chemical products	LAYER 1 C	Chemicals	8.7	1.7%
Electricity, gas and water supply	LAYER 3 I	Computer, Elecronic and optical	8.7	1.6%
Electricity, gas and water supply	LAYER 3 I	Machinery and equipment	8.5	1.6%
Electricity, gas and water supply	LAYER 2 C	Textiles	8.4	1.6%
Transport and storage	LAYER 2 C	Wholesale and retail trade	6.5	1.2%
Fabricated metal products	LAYER 2 I	Construction sector	6.5	1.2%
Electricity, gas and water supply	LAYER 2 C	Wholesale and retail trade	6.2	1.2%
Electricity, gas and water supply	LAYER 2 I	Computer, Elecronic and optical	5.9	1.1%
Other non-metallic mineral products	LAYER 2 I	Construction sector	5.8	1.1%
Electricity, gas and water supply	LAYER 2 I	Machinery and equipment	5.6	1.1%
Electricity, gas and water supply	LAYER 3 C	Wholesale and retail trade	5.5	1.0%
Electricity, gas and water supply	LAYER 3 C	Computer, Elecronic and optical	5.4	1.0%
Transport and storage	LAYER 1 I	Transport and storage sector	4.7	0.9%
Machinery and equipment, nec	LAYER 1 I	Machinery and equipment	4.6	0.9%
Electricity, gas and water supply	LAYER 3 C	Chemicals	4.5	0.9%
Textiles, textile products, leather and footwear	LAYER 1 C	Textiles	4.4	0.8%
Electricity, gas and water supply	LAYER 2 C	Chemicals	4.4	0.8%
Chemicals and chemical products	LAYER 1 C	Chemicals	4.2	0.8%
Electricity, gas and water supply	LAYER 3 C	Manufacturing nec	4.2	0.8%
Transport and storage	LAYER 2 C	Transport and storage sector	3.7	0.7%
Electricity, gas and water supply	LAYER 2 C	Computer, Elecronic and optical	3.6	0.7%
Chemicals and chemical products	LAYER 3 C	Textiles	3.4	0.6%
Chemicals and chemical products	LAYER 2 C	Textiles	3.4	0.6%
Chemicals and chemical products	LAYER 2 C	Health and social work sector	3.3	0.6%
Electricity, gas and water supply	LAYER 3 C	Health and social work sector	3.3	0.6%
Electricity, gas and water supply	LAYER 2 C	Manufacturing nec	3.1	0.6%
Fabricated metal products	LAYER 2 I	Construction sector	3.1	0.6%
Transport and storage	LAYER 3 I	Construction sector	2.9	0.5%
Electricity, gas and water supply	LAYER 3 I	Other transport equip	2.7	0.5%
Transport and storage	LAYER 2 I	Construction sector	2.5	0.5%
Electricity, gas and water supply	LAYER 3 I	Electrical machinery	2.4	0.5%

Fabricated metal products	LAYER 1 I	Fabricated metal	2.3	0.4%
Chemicals and chemical products	LAYER 3 I	Computer, Elecronic and optical	2.1	0.4%
Transport and storage	LAYER 2 I	Wholesale and retail trade	2.1	0.4%
Electricity, gas and water supply	LAYER 2 I	Wholesale and retail trade	2.1	0.4%
Electricity, gas and water supply	LAYER 3 I	Motor vehicles, trailers	1.9	0.4%
Electricity, gas and water supply	LAYER 3 I	Wholesale and retail trade	1.7	0.3%
			215.9	**40.9%**