Carbon Tax and Emissions Transfer a Spatial Analysis

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Abstract

Finding the best way to reduce pollution in a world with growing environmental concerns is important for decisions makers. Some scholars hold that a global carbon tax is the best policy for reduced pollution. With the rising role of globalization, assessing the impacts of carbon taxation on carbon emissions embodied in the trade becomes a key question, however, this question has been overlooked. This is the first paper to bridge this gap. More specifically, our contribution consists of examining an emission tax system of trade, in the framework of the input-output table. We exploit variation in the economic sector of each country to first, identify the most and fewer contaminated categories, and second, investigate the spillover effects due to carbon taxes in an emission embodied in trade analysis. Based on the SDA (structural decomposition analysis), MRIO (multi-regional input-output model), and spatial econometric models, we estimate the spillover effect of emissions embedded in the trade before and after a carbon tax is in place, this for 5 categories, 56 sectors, 43 countries from 2000 to 2014. Our findings prove the "Electricity and Heat Production" as the highest emitter category and reveal a spillover effect of polluting production in their intermediate sectors. When countries impose a carbon tax, which is different in size by country, the effect of emissions embedded in exports and imports will decrease 0.25 percent (from 0.0823 to 0.0798) and 0.36 percent (from 0.0579 to 0.0543) respectively, to and from neighboring countries (with the geographical distance matrix). When studying the trade comparative advantage matrix, the results are smaller but still positive 0.011 percent (from 0.00307 to 0.00318) for exports and -0.059 percent (from 0.00301 to 0.00242) for imports. Our results show that carbon tax could displace pollution to neighboring countries when taking into account the trade matrix (comparative advantage). This should be taken into account by policymakers. Establishing regional or neighboring taxes might be a solution to avoid pollution leaks and to obtain better results in reducing pollution.

Keywords: `Carbon tax, Trade emission, MRIO, Spatial econometric.`

JEL codes: C31, Q20, Q43, Q56, R12, R15.

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1 Introduction

Since the industrial revolution, extreme CO_2 emissions by producing and consuming goods and services began to cause severe damage to the environment. As a consequence in this era, the accelerated increase in fossil fuels consumption and of Green House Gases (GHG) emissions has sprung an environmental problem up, that of global warming and climatic instability: rise in water level, melting of polar ice caps, ... Global carbon emissions from fuel combustion has increased by 3.9 billion tons in the last decade (IEA, 2019). In order to tackle these problems, governments of 36 and 189 countries contract the Kyoto protocol and the Paris agreement, respectively.[1] Generally, Carbon Tax is the most recurring tool in order to decrease emissions ((Kotlikoff et al., 2019)). So when the carbon tax (like the environmental tax) rate rises, carbon dioxide concentration will theoretically decline (Sundar et al., 2016).[2] Meanwhile, when a carbon tax is implemented by a government, the country tends to import goods intensive in carbon rather than producing them domestically with clean technology. To reduce trade costs, fixed and variable costs of producing them, goods tend to be imported from neighboring countries; that is: at low geographical distances. In previous years, tax implementations have caused an increase of the emissions embodied in exports and imports, of around 5% and 10%, respectively (see tables 2 and 3).

Carbon emissions affect the neighborhood (spatial impact) in two ways:

1. Countries by producing goods and services emit pollution at the national level, and this pollution is transmitting to neighboring countries through exports.

2. In order to avoid paying the carbon tax, countries transfer the production of their output to tax-exempt third countries, because the imported goods from that country might be exempted from the tax. This is what we will capture in this paper.

Several studies probe the empirical policy in line with the dwindling rate of CO_2 emissions in trade and link to international displacement of production. They focus on the impacts of the

[1] "The 1997 Kyoto Protocol introduced a market-based approach for the reduction and control of greenhouse gases. The 2015 Paris Agreement greatly broadened the set of tools to address carbon emissions and climate change, to include green financing and trading in green bonds, as well as regulatory and fiscal instruments" (Conway et al. (2017)).

[2] In most countries, the carbon tax is known as an environmental tax (Clough, 2016). In the rest of this paper, we will talk about the carbon tax referring to environmental tax.

transition pathways to decline carbon emission.[3] In other studies, offset emission abatement leads to even higher overall emissions [4], while other works disagree.[5] The econometric results of studies such as Guan et al. (2019), Zhong et al. (2018), Karnizova (2016), da Silva Freitas et al. (2016), Perobelli et al. (2015), Kulionis (2014), Du et al. (2011), and C. Wu et al. (2015) show that the input–output linkages play an important role in explaining the observed volatility of carbon emission embodied in trade.

Generally, the multi-sector model captures the volatility and the interaction of variables in intermediate (for instance "Electricity and heat production") and final sectors. It shows how much pollution is produced directly and indirectly in each category. So, it is particularly well suited for environmental policy analysis. Hence, Yan et al. (2016) studies three important reasons for using the input-output model:

1. Ex-ante analysis can be carried out and serve as an effective tool in quantifying key coefficient changes to CO_2 emissions.
2. Dependency and proportionality relations between different sectors can be exposed.
3. The model is very tractable, because of the interactions of intermediate sectors and final sectors.

Examining geographic space allows following the effect of propagation emissions from trade (G. Chen et al. (2017) and Zhong et al. (2015)). Currently, with the rise in international trade and the widening in geographic separation between production and consumption, regional trade happens to be one of the core factors of the transfer of carbon emissions. The richest countries become net carbon importers while developing countries become net carbon exporters (G. Chen et al. (2016) and Kanemoto et al. (2014)). Nevertheless, scholars barely discuss the influences of carbon taxation on trading emission embodied behaviors, while the way by which carbon taxation influence emitting countries, in achieving compliance with commitments to reduce emissions, is still debatable.

[3]e.g. S. Wang et al. (2019); Q. Wang & Zhou (2019b); Fan et al. (2019); Ding et al. (2018); Long et al. (2018); Sakai & Barrett (2016); Matsumoto (2015).

[4]see e.g. McEvoy & McGinty (2018); Asselt & Brewer (2010); Elkins & Baker (2001)

[5]see e.g. Ren et al. (2020); Bi et al. (2019); Cao et al. (2019); Z. Zhang, Zhang, et al. (2017) and Baylis et al. (2013).

This paper's contribution to the literature is threefold. First, we perform a quantitative analysis of the share of pollution in five different categories and its diffusion to other intermediate sectors. Second, we fulfill the spatial effect of independent variables (GDP, consumer and producer emission, and share of clean energy) on emissions embodied in exports and imports. Third, we accomplish a quantitative analysis of the share of pollution and its diffusion, from the host country to neighboring countries, and we add the pollution displacement to quantify the total CO_2 carbon particles in the global atmosphere.

In the first part the quantitative by sector analysis, since previous research overlooked the spatial impact of emissions, we decide to study this in-depth, it will be the core of our research question. So far the literature use input-output model; and does not include the spatial effect into the multi-regional input-output model (Perobelli et al. (2015), J. Guo et al. (2018), W. Chen et al. (2017), Q. Wang & Zhou (2019b), S. Wang et al. (2020), and Q. Wang & Yang (2020)). We integrate all 43 countries (31 OECD countries plus 12 major other countries) into 56 sectors, then amalgamate the sectors into 5 categories and examine the effects of pollution in each category. In doing so, as found in most studies, we confirm that "Electricity and heat production" is the category emitting the most CO_2 (see Appendix A table 2).

Secondly, the development of international trade, in recent years, allows the emissions to be transferred from one country to another through carbon in goods. We investigate spatial econometric methods in order to capture this emissions displacement due to differences in carbon tax. More specifically, our specification aims to tackle the effect of carbon taxation on carbon embodied emissions in trade by considering both the host country and its neighboring countries. In so doing, we aggregate the 56 sectors and study their effect by country (see table Table 5 in Appendix B).[6] The largest amount of emissions embodied in all sectors of production for export and import belong to the United States over the period of 2000- 2014. It has also paid the most taxes among the countries surveyed. Based on emissions embodied in trade and environmental tax in this table, it is obvious that pollution diminution task between countries is still incredibly difficult in tackling climate change. Afterward, we identify the existence of a spatial correlation between economic

[6] The basic carbon taxes and emissions trading approach are outlined by Elliott et al. (2010), Ekins (2009), Elkins & Baker (2001), and emission taxes without considering interact between countries are implemented in part by Ren et al. (2020), Guan et al. (2019), Mardones & Flores (2018), McEvoy & McGinty (2018), da Silva Freitas et al. (2016), Karnizova (2016), Marron & Toder (2014), McLure (2014).

variables (GDP, consumer and producer emission and share of clean energy, etc.) of a given country and its neighboring countries. This allows us to analyze the general spillover effect of our dependent variables, Emissions Embodied in Exports (EEE) and Emissions Embodied in Imports (EEI), and also to observe the effect of the independent variables on our dependent variables (EEE and EEI).

In a third step, in the presence of spillover effects and relying on spatial econometrics, we measure the level of those spillover effects within the variation of pollution after a carbon tax. In this part, we can learn about the pollution effect of the host country and the spillover effect of the independent variables.

The remainder of the paper is structured as follows: section 2 presents the state of the art of the literature. Then, the spatial growth model, the spatial weight matrix, and the hypotheses tests, covering both theoretical and empirical issues are explained in section 3. The estimation strategy and data are shown afterward in section 3. Section 4 discusses the estimation results, section 5 conclude and in section 6 we give policy recommendations.

2 Literature review

The current study of international CO_2 emission transfers is synthesized into two different strands. The first strand measures CO_2 emissions embodied in trade that are generated by goods and services produced in some countries which are consumed in other countries (Peters et al., 2012).[7] The second strand of the literature analyses the carbon that is physically in fossil fuels, petroleum-derived products, harvested wood products, crops, and livestock products (Peters et al., 2012).[8] In this paper, we only scrutinize the first strand. This strand studies, the CO_2 emitted from the production of goods and services are mitigated in one country as it rises in other countries via international trade through two hypotheses:

- Displacement Hypothesis: Developed countries produce low-carbon goods while dirty production is concentrated in developing countries, without altering consumption patterns (Dinda (2004) and Cole et al. (2000));

[7] see e.g.PU et al. (2020); X. D. Wu et al. (2020), and Bushnell & Mansur (2011)

[8] see e.g. Q. Wang & Yang (2020); W. Chen et al. (2017); Wiedmann (2016), and Peters (2010).

- Pollution Haven Hypothesis: Developed countries will lose all the contaminants, and developing countries will get them all, this is due to differences in environmental regulation. In other words, a country with weak environmental regulations may attract foreign investors in polluting activities. For example, Mexico has become a pollution haven for the United States battery industry.[9]

For the matter of our study, these two hypotheses are practically the same if we analyze them in terms of comparative advantage in international trade (Dinda (2004)). They assume, on the one hand, that environmental protection is not the priority of poor countries. Since, poor countries want to develop, receiving international investment even for dirty production, can be appealing. On the other hand, poor countries do not have strong carbon tax regulations, so rich countries target these countries to displace their production of dirty goods to reduce their costs. In this scenario, the developing country is chosen as a market for the production of high-carbon goods.

These hypotheses illustrate that pollution is being displaced from one country to another, rather than being reduced when regulations are strengthened, such as taxes (Dinda (2004)). They also assume that increasing environmental regulations in all countries (for example, imposing the same tax for all) will raise the production cost of high-carbon goods overall. In this case, the manufacturing firm has to pay a fixed cost for settling the factory and producing and a variable cost of transporting manufactured goods (imports). A carbon tax will increase both the fixed and variable costs of the plant. As a consequence, the comparative advantage for producing dirty goods in neighboring countries is reduced.

Therefore, according to these hypotheses, the study of geographical and trade effects between countries is very important because it shows that pollution is moved between countries like a network. As for the indicators of the emissions we have: 'emissions embodied in exports, and 'emissions embodied in imports. They are used to calculate the trade-embodied emissions that cause environmental impacts.

One of the best solutions to decrease greenhouse gases (GHG) is to tax emissions according to

[9]https://www.ohchr.org/Documents/Issues/ToxicWaste/RightToInformation/OccupationalKnowledgeInternational1.pdf

the amount of CO_2 emitted by different sectors (Urata et al., 2017). Taxation is also a financial tool that is well considered by most policymakers (Fahimnia et al., 2015). Hence, we can anticipate that an emission tax provides economic motives to reduce pollution for producers that have no intention to protect the environment.[10]

Due to vast data requirements, and the important number of countries involved in the management of such a system, there is no worldwide accepted methodology to calculate carbon content (McLure, 2014). In theory, there exist three ways by which levying carbon taxes can equalize countrywide pollution level ((Ding et al., 2018)):

1. All countries simply levy the same tax on the carbon content of fossil fuels produced within their borders.

2. The production tax base could be modified to include fuel imports taxes to equalize them when production tax is lower in the producing country.

3. Destination-based taxation of emissions is a more complicated solution. In order to minimize the cost of producing, certain factories have moved closer to the related customers, perhaps in a developed world, and hence it may be very difficult to identify between various taxes which one has led to the choice of a new destination to manufacture goods.

The core model for estimating the CO_2 emissions embodied in trade is input-output analysis (IOA). This model relies on emissions produced due to energy used in each intermediate consumption and production by sector ((Ding et al., 2018)). We then matched with the corresponding export and import of goods and services (See Appendix B Table 1). Insofar as we consider emissions at the global level which is the result of export and import of goods and services for consumption and production, our work contributes to the literature, in the following way:

- Calculating carbon emissions embodied in trade, as part of carbon transfer magnitude, to quantify direct or indirect carbon emissions;

- Building a multi-regional input-output model (MRIO) and analyzing the spatial spillover effect of taxation on carbon emissions embodied in trade;

[10]The first country to implement a carbon tax for abatement of the output of greenhouse gases and carbon dioxide is Finland, in 1990, which levy currently stands at 24.39 dollars per ton of carbon. After one year Sweden and Norway both have implemented their carbon taxes and Denmark has followed, in 1994.

- Considering the magnitude of pollution of different sectors.

In the structural decomposition analysis, the two situations before and after-tax are discussed, and suggestions are provided to achieve carbon emission reduction through taxation for the countries in the sample (see section 4.2 Spatial Model). In other words, we focus on estimating carbon tax and abatement trade emissions and the share of direct and indirect emissions in different economic categories over fifteen years. In addition, we investigate the impacts of carbon emissions before and after-tax on the host country and neighboring countries. The latter analysis, to the best of our knowledge, is currently absent in the literature (see Appendix A Table 1).

3 Methodology

With the approach of the input-output method analysis (IO), the economic effect of emissions of carbon is measurable. The Emissions Embodied in Bilateral Trade (EEBT) system are generally used to calculate an inter-regional trade scale of emissions. MRIO model describes the ties between foreign industries of a country, taking into account trade between intermediate and final products and services, for an assessment of emissions along the global supply chains. In particular, greenhouse gas emissions are determined by electricity consumption in the final demand for goods and services. Separate research offers a methodology to explore the implications of direct trading for emissions (see Section 4.2 Spatial Model).

This section seeks to assess the pollution differences of the carbon tax. It means that the costs of production fluctuate, this will represent higher prices. Pricing is the central element in the model for final and intermediate goods.

In our world, we need to take into account the fact that trade pollution and carbon taxes do influence surrounding areas. Spatial dependence matters. The techniques of spatial regression are then the proper method of estimation. Spatial measurements are used to decide whether the data are spatially related. We then use the Log-Likelihood function to see what spatial model is best suited to our data collection.

If the dependent variable changes its direct influence in some cases, each diagonal aspect of the matrix of the partial derivatives often contributes to changes in the dependent variables in other situations.

In this section, we also present our data and show summary statistics. We analyze 43 developed and emerging countries based on a spatial panel data model, data cover the 2000-2014 period.

3.1 Data

In this section, we present our data and show summary statistics. Our work, based on the spatial panel data model, analyses 43 countries.[11] These countries were chosen to have a mix of developed and emerging economies. Complete data in the world input-output database (WIOD) were available for those countries which happen to be the highest pollution emitters in the share of their GDP. The data covers the period 2000-2014. All the data were transformed to the natural log before using them for analyses. Economic data such as intermediate inputs, final demands, and per capita GDP are in 2016 constant prices (US dollars). The descriptive statistics of variables are presented in Table 1.

Table 1: Measurement and Descriptive Statistics of Variables

Variable	Definition	Unit	Mean	Std.Dev.	Min	Max
EEE	Emissions embodied in exports	Mt	3.4874	1.7788	0.1344	10.5868
EEI	Emissions embodied in imports	Mt	1.8087	1.5514	-1417	6.4543
TAX	carbon tax	Million dollars	8.4638	2.0382	0	11.70127
TEBT	Total emissions before tax	Mt	11.7661	2.7111	4.8204	20.0515
TEAT	Total emissions after tax	mt	8.999	2.8979	1.807	18.0747
IPI	The tax impact on price index	Million dollar	3.6664	3.0262	-5.4033	9.4406
GDP-engi	GDP per unit of energy consumption	Million Dollar/Mt	-11.7465	0.3556	-13.0163	-10.8619
Clean-engi	The ratio of clean energy to total energy use	%	2.3358	1.1753	-2.4383	4.4784
PGDP	Per capita GDP	Million dollars	9.8501	1.0322	6.1983	11.5351
Intermediate-Local	Intermediate inputs in local region	Million dollars	12.5772	1.7475	8.2934	16.8424
Final-Local	Final requirements in local region	Million dollars	12.5545	1.7635	8.4225	16.6653
Intermediate-Other	Intermediate inputs in other regions	Million dollars	9.6786	1.5616	5.3796	13.2202
Final-Other	Final requirements in other regions	Million dollars	9.1475	1.663	4.5644	13.0963
C-emission	Consumer Emissions	Million dollars	17.4695	3.3585	9.188	26.1566
P-emission	Producer Emissions	Million dollars	14.9916	3.1469	6.6068	23.1412
OECD	Belonging to an OECD country	Dummy Variable	0.7209	0.4489	0	1

Author's calculation based on dataset.

[11]countries included are Australia, Austria, Belgium, Brazil, Bulgaria, Canada, China, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Hungary, Greece, Indonesia, India, Ireland, Italy, Japan, Latvia, Lithuania, Luxembourg, Malta, Mexico, The Netherlands, Norway, Poland, Romania, Portugal, Russian Federation, Slovakia, Slovenia, Spain, Sweden, Switzerland, Taiwan, The Republic of Korea, Turkey, United Kingdom, and the United States.

3.2 Stylized facts

3.2.1 Coefficient of Share of Direct, Indirect and total Carbon Emission

SDA (structural decomposition analysis) is based on the input-output model and, thus, gives information regarding the economic structure. Moreover, the SDA has the benefit of apprehending the direct and indirect impact as taken through the Leontief matrix of the input-output models. Besides, the SDA allows evaluating the impacts of the emissions embedded in trade on the economic structure, rather than the unconventional change of each sector. Actually, the transition can be decomposed into many different sections for a systemic decomposition study on the change in carbon emissions integrated with the SDA method trade. Afterward impact of these aspects on the carbon emissions embodied in trade is then analyzed. The decomposition form is not special according to SDA methods, and can normally be overcome with the method of decomposition of polarization or a mean value method. In this paragraph, we propose a structural decomposition analysis of the share of pollution in five different categories to assess the amount of emission of each industry. Subsequently, we highlight the main and less polluting categories for CO_2. [12]

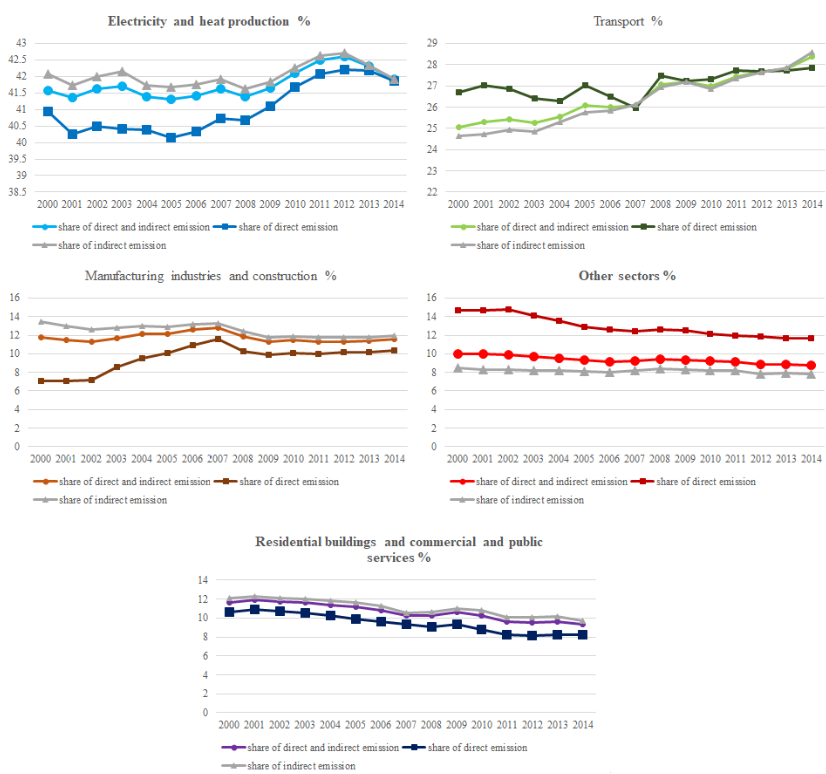
Direct effects show how much pollution is produced in each category. Indirect impacts indicate how much contamination is created by the intermediate products used to produce in each sector. Total effects include all pollution from the production of goods, whether pollution from the production of goods or pollution from the intermediate goods used in production. According to the total CO_2 emissions and the total output of various categories, the share of direct, the share of indirect, and the share of total carbon emission factors based on ISIC code, we decompose all sectors in the Input-Output table into five specific categories from 2000 to 2014. The results of calculations are shown in figure 1.

The coefficient of the share of direct, indirect, and total emission in the same year of different categories could differ significantly from an increasing trend. The category with the largest coefficient of direct, indirect, and total carbon emission for all years is "Electricity and heat production". As J. Guo et al. (2018) says, *"They provide necessary intermediate products or secondary energy*

[12] We effort to use the IPCC (Intergovernmental Panel on Climate Change) database to calculate the figure of coefficient carbon emissions based on 56 sectors that do not correspond to the input-output table database of WIOD (World Input-Output Database). Therefore, we classified the sectors in terms of 5 categories in which carbon data was available.

to other sectors and emitted more CO_2 in the direct production process. Hence, there is an urgent need to improve their energy use efficiency and emission intensity". The category with the smallest coefficient of indirect and total carbon emission for all years is "Other sectors" but for the coefficient of direct carbon emission for 2000- 2004 it is "Manufacturing industries, construction", and for 2005-2014 it is "Residential buildings, commercial and public services". The largest coefficients of the direct, indirect and, total emission were 42.6, 42.2, and 42.7 in 2012, respectively, signifying an increasing trend of the inter-sectoral coefficient. The smallest coefficient total emission was 8.8 in 2014, for direct emission, it was 7.1 in 2001 and for indirect emission, it was 7.8 in 2012. Thus, the industries have continuously elevated the level of production technology and energy use and some results of energy-saving and emission reduction have been achieved in some sectors because of more attention paid to the environment.

Figure 1: Share of Direct and Indirect Emission in Each category



Source: Author's calculation

3.3 Emissions Embodied in Bilateral Trade (EEBT) and the Multi-Regional Input-Output (MRIO)

Direct and indirect (complete) economic impacts of carbon emissions could be measured by the Input-output (IO) method analysis, which also analyzes the interdependence between production factors, such as the intermediate input and final requirements in a particular activity/sector. It thus permits the calculation of the direct and indirect environmental impacts of products and provides a quantitative estimation of pollutants. Through this model, we can accurately calculate the regional and inter-regional GHG emission rates, and also evaluate the inter-linkages between different sectors, Thus it is recognized as a powerful tool for estimate changes in pollution.

Two essential methods contributed to calculating pollutant emission the EEBT and the MRIO model. The EEBT model is applied to evaluate pollutant emissions in bilateral trade and inter-regional bilateral trade. The MRIO model identifies the links between international industries to estimate the pollutant emissions along the global supply chains, taking into account trade in both intermediate inputs and final goods and services. The EEBT method is usually employed to measure the scale of pollution embodied in inter-regional trade (S. Wang et al. (2019); B. Zhang et al. (2016)). In the MRIO model, the intermediate demand coefficient (A) matrix merely contains the domestic components, while in EEBT, intermediate exports are added as column vectors along with final demand.

The MRIO model calculates how the various economic activity sectors react to a variation in the final demand for goods and services during a given period within a national economy. The core of the MRIO model is the Input-Output Tables, which represent the trading connections among the different industries (intermediate consumption) as well as with households (final consumption), expressed in price. This model considers the relationship between multi-regional units and the inter-regional connection between them over time. The MRIO approach uses data for three elements: each region's input-output table, each region's export level to the world, and each region's CO_2 emissions data. The MRIO research allows to measure inter-regional trade volumes of various goods and to describe the economic ties between regions and sectors, in-depth. This model is the preferred model for scientists, as it permits the analysis of the trade-related carbon relations between different countries or regions. For instance, the separate studies showed that the most significant sources of pollution are the energy market and then both household and government consumption. Government should introduce initiatives to facilitate public investment in the form of green consumption, such as constructing public green buildings to mitigate CO_2 emissions S. Guo et al. (2020); Su et al. (2017) and Su & Thomson (2016).

Z. Zhang & Hewings (2014) offer a methodology to compute the pollution haven hypothesis with the EEBT method to investigate the consequences of direct trade without regarding the inter-regional feedback impacts. Thus, the EEBT method is half-done as a consumption-based method. In contrast with the EEBT method, the MRIO method takes the whole inter-regional supply chain and relevant spillover and feedback impacts. The MRIO method extensively investigate China's region-specific greenhouse gas emissions B. Zhang et al. (2016); Zhao, Liu, et al. (2016); Xie et al. (2015)) and other environmental emissions (Lv et al. (2019);F. Wang et al. (2017); Li et al. (2016); S. Y. B. Chen & Fath (2015).

Insofar as we are interested in inter-regional relations, as we are considering the impact of pollution on neighboring countries/regions, we will rely on the MRIO model.

$Z^{r,s}_{ijt}$ represents the intermediate transfers from sector i in the region r produced to meet the needs of sector j in the region s in year t, and $r, s = 1, 2, \ldots 43$ and $i, j = 1, 2, \ldots 56$ in input-output approach ($i \neq j, r \neq s$). $A^{r,s}_{ijt}$ presents the direct consumption coefficient (the Leontief coefficient). According to IO (input-output) theory (Miller & Blair, 2009), equilibrium among the column and the row in the IO table is showed as:

$$X^r_r = \sum_{s=1}^{N} Z^{rs}_r u + \sum_{s=1}^{N} F^{rs}_r \tag{1}$$

F^{rs}_r represents the matrix of final demand for each region. It can be simplified by using a identical matrix expression for all region: $X_t = Z_t u + F_t u$ and $X_t = A_t X_t + F_t u$.

Carbon emissions V_t can be assumed as follows:

$$\mathbf{V_t} = \begin{matrix} (W_t^1)'M_t^{1,1} & \cdots & (W_t^1)'M_t^{1,n} \\ \vdots & \ddots & \vdots \\ (W_t^n)'M_t^{n,1} & \cdots & (W_t^n)'M_t^{n,n} \end{matrix} \tag{2}$$

Where $v_{i,t}^{rs}$ is the coefficient of the total carbon emission, expressing the total quantity of the direct and indirect CO_2 released by the output of the production sector i, in year t and region r, s (the unit of measure is tons). It can be obtained as follows: $w_{i,t}^r = e_{i,t}^r / X_{i,t}^r$, with $e_{i,t}^r$ an element of the matrix describing the volume of the emissions; each element is then divided by the final output of each sector.

Where $M_t^{r,s} = (1 - A_t)^{-1}$ represents the coefficient of total relationships between regional sectors; It is a Leontief inverse matrix (Wassily, 1986).

With all of the equations above we can accurately measure the total CO_2 emissions (see equation 3) and distinguish between carbon emissions created by the demand of the region r for the local production of the region r, and emissions embodied in exports from the region r towards region s in year t, (see equation 4, where $r, s \in N$,N=1, 2,. . . 43).

$$E_{r,t}^T = E_{r,t} + E_{r-s,t} \tag{3}$$

$$E_{r,t} = \left[\sum_{k=1}^{N} (v_t^{kr})' \right] f_t^{rr} \tag{4}$$

$$E_{r-s,t} = \left[\sum_{k=1}^{N} (v_t^{kr})' \right] f_t^{rs} + (v_t^{rs})' \left(\sum_{k=1}^{N} f_t^{rk} \right) \tag{5}$$

Where $E_{r-s,t}$ expresses the CO_2 emissions for the final product exported from region r towards another consuming region; that is carbon emission which are embodied in exports.

$\sum_{k=1}^{N}(v_t^{kr})'$ is a row vector of CO_2 created in all region that is required for (and thus embodied in) one unit of the final commodity produced in a particular sector k in region r; f_t^{rs} defines, for each sector, the final good and services produced in region r for final users of another region s; the term $(v_t^{rs})'(\sum_{k=1}^{N} f_t^{rk})$ shows the amount of CO_2 emissions from an intermediate good produced in the region r that is sent to other economic sectors for production in other regions. Emission embodied in trade (EET) for any region r consist of emissions embodied in imports (EEI) and emissions embodied in exports (EEE) (Serrano & Dietzenbacher, 2010), that are expressed as below:

$$EEE_r = \sum_{s\neq r}^{N} EEP_{r-s} = \left[\sum_{k=1}^{N}(v_t^{kr})'\right]\left(\sum_{s\neq r}^{N} f_t^{rs}\right) + \sum_{s\neq r}^{N}\left[(v_t^{rs})'(\sum_{k=1}^{N} f_t^{rk})\right] \quad (6)$$

$$EEI_r = \sum_{s\neq r}^{N} EEP_{s-r} = \sum_{s\neq r}^{N}\left[\sum_{k=1}^{N}(v_t^{kr})'\right] f_t^{sr} + \left[\sum_{s\neq r}^{N}(v_t^{sr})'\right]\left(\sum_{k=1}^{N} f_t^{rk}\right) \quad (7)$$

Using equation 6 and equation 7, we can calculate the amount of pollutant emission generated from exports and imports. Moreover, from these equations, we can deduce the proportion of pollutant emission from exports of the region r to other regions, identify the source of the pollutant present in a particular region and find the difference between the emissions from bilateral trade (J. Guo et al. (2018) and Zhong et al. (2018)).

In equation 6 and equation 7, EEP_{r-s} and EEP_{s-r} show emissions embodied, respectively, in export and import from regions r to region s.

Then the trade balance of CO_2 emissions embodied is used as a representation to explain the "carbon leakage" between region r and region s (Peters & Hertwich, 2008). It can be expressed as follows:

$$E_{r,t}^{BEET} = EEE_{r,t} - EEI_{r,t} \quad (8)$$

According to Peters & Hertwich (2008), total production emissions inventory from production are equal to emissions from trade expressed as follows:

$$E_{r,t}^{P-emission} = EEE_{r,t}^{T} \tag{9}$$

Similarly, consumption emission inventory is measured as total emission produced minus the balance of CO_2 emissions embodied in trade:

$$E_{r,t}^{C-emission} = EEE_{r,t}^{T} - EEI_{r,t}^{BEET} \tag{10}$$

3.4 Tax

In the literature related to the input-output table, two price models allow measuring the impact of price changes on the whole economy: the Ghosh and the Leontief price models (Ghosh (1958); Leontief (1941) and Leontief (1966)). These models show the effect of variations in the price of intermediate production on economic sectors, and the final price value of production factors in consuming activities (Georgescu-Roegen (1951) and Ghosh (1958)). This strand of research aims to measure the impact of green tax on emission variations. It assumes that it leads to fluctuations in production expenditure which induce an increase in prices. According to the pricing model, the demand for the final and intermediate products is the essential factor of price setting (da Silva Freitas et al. (2016) and Phungrassami & Usubharatana (2019)). The prices, weighted by the ratio of the sum of input expenditure to the value-added can be expressed as equation (11):

$$X_{i,t}^{r} = i^{'} A X_{t}^{rr} + (V_{i,t}^{r,s})^{'} \tag{11}$$

If the value-added vector and each of the elements of the matrix A are in monetary value, then the value-added raw vector v described the monetary value of output in value-added. To solve equation 12 we post-multiply the coefficient of A matrix by a price vector P, equal to a raw vector of items in equation 14. Then given $(I - A)^{-1} = L$, we find.

$$P_{t}^{r} = (I - A^{'})^{-1} V_{t}^{u,r} = (L_{t}^{r,s})^{'} V_{t}^{u,r} \tag{12}$$

If the government implements an equal tax on the amount of emitted CO_2 in each productive sectors (industrial activity), the tax vector T can be expressed by the following equation:

$$T_t^r = \varphi_t^r V_t^{r,s} x_t^{r,r} \tag{13}$$

Where φ is the rate of CO_2 equivalent per ton coming from all sectors polluting in region r, and $x_t^{r,r}$ is the final output of all sectors in region r.

Hence, the rate of total emission tax of the output is calculated as follows:

$$\tau_t^r = T_t^r (x_t^{r,r})^{-1} \tag{14}$$

As we said before any tax increased the prices, so the adjusted price vector is:

$$\tilde{P}_t = (L_t^{s,r})' (V_t^r + \tau_t^r).\tilde{p}_t^r - \tilde{P}_t^r \tag{15}$$

As mentioned before, total emissions intensity before tax can be represented by the previous equation related to the sectors, $V_{i,t}^r = e_{i,t}^r / X_{i,t}^r$, where $e_{i,t}^r$ is a vector expressing total sector emissions and $X_{i,t}^r$ indicates the total output of industrial activities.

Following Gemechu et al. (2014), variations in sectoral output prices caused by the tax could also affect the total productive sectors' output. Such impacts can be estimated by considering that the monetary values of output before and after the implementation of the tax were maintained at their initial levels. Therefore, the new change of the sectoral output j after the new tax (X_j) can be calculated as:

$$X_{j,t=1}^r = \frac{\tilde{P}_{t=0}^r}{\tilde{P}_{t=1}^r} X_{j,t=0}^r \tag{16}$$

Where $\tilde{P}_{t=0}^r$, is the price index for the base year and $\tilde{P}_{t=1}^r$ is the new price after inclusion of the tax. Total emissions after tax are estimated as:

$$e_{i,t}^r = (M_t^{r,s})'.X_{j,t=1}^r \tag{17}$$

Where $X^r_{j,t=1}$ is the new final output and $(M^{r,s}_t)'$ represents the total coefficient relationships between sectors; it is a Leontief inverse matrix.

The impact on the industrial price index (IPI) is presented by:

$$IPI_t = \sum_{j=1}^{43} \tilde{P}_t a_{t,j} \tag{18}$$

where $a_{t,j}$ is the technical (Leontieff) coefficient indicating the ratio of intermediate consumption of industry j product on the total output (da Silva Freitas et al., 2016).

3.5 Spatial model

The hypothesis that trade emissions and emission tax have no impact on neighboring regions does not fit to the reality of our world. We observe spatial dependency. Then, the spatial regression methods are the adapted estimation method.

In our study, we use SAR (Spatial Lag Model), SEM (Spatial Error Model), SDM (Spatial Durbin Model), and SAC (Spatial Autoregressive Model). Before building the spatial econometric model for the impact of tax on emissions embodied in trade, the existence of the spatial effect must be tested. We utilize a log-likelihood test derived for spatial panel data. In this test, whether or not the non-spatial model can be rejected is determined by the significance of the statistics. We use spatial tests[13] to identify whether there is a spatial correlation between the data, justifying the implementation of spatial regressions. Then we use the Log-Likelihood Function to know which spatial model gives the better fit for our data set.

Scholars have used different measurement methods and appropriately introduced other explanatory variables to conduct extensive discussions on the relationship between the emissions embodied in trade and taxation. Based on the theoretical and empirical literature, the spatial panel data model we use is as follows equation 19:

[13]The various spatial tests used are: LM (Lagrange multiplier) test, LR test, Wald test, Moran MI Error Test.

$$LnY_{ijt}^{rs} = \beta_0 + \lambda W_{t-1}^{rs} LnY_{ijt}^{rs} + \beta_1 LnT_{ijt}^{rs} + \beta_4 LnGDP.engi_t^{rs} + \beta_5 LnClean.engi_t^{rs} + \beta_6 LnPGDP_t^{rs} + \beta_7 LnIntermediate.Local_{ijt}^{rs} + \beta_8 LnFinal.Local_{ijt}^{rs} + \beta_9 LnIntermediate.Other_{ijt}^{rs} + \beta_{10} LnFinal.Other_{ijt}^{rs} + \beta_{11} LnC.emission_{ijt}^{rs} + \beta_{12} LnP.emission_{ijt}^{rs} + \beta_{12} OECD + \delta_1 \sum_{ij=1}^{n} W_{ij} LnT_{ijt}^{rs} + \delta_4 \sum_{ij=1}^{n} W_{ij} LnGDP.engi_t^{rs} + \delta_5 \sum_{ij=1}^{n} W_{ij} LnClean.engi_t^{rs} + \delta_6 \sum_{ij=1}^{n} W_{ij} LnPGDP_t^{rs} + \delta_7 \sum_{ij=1}^{n} W_{ij} LnIntermediate.Local_{ijt}^{rs} + \delta_8 \sum_{ij=1}^{n} W_{ij} LnFinal.Local_{ijt}^{rs} + \delta_9 \sum_{ij=1}^{n} W_{ij} LnIntermediate.Other_{ijt}^{rs} + \delta_{10} \sum_{ij=1}^{n} W_{ij} LnFinal.Other_{ijt}^{rs} + \delta_{11} \sum_{ij=1}^{n} W_{ij} LnC.emission_{ijt}^{rs} + \delta_{12} \sum_{ij=1}^{n} W_{ij} LnP.emission_{ijt}^{rs} + \delta_{13} \sum_{ij=1}^{n} W_{ij} OECD + U_{ijt}^{rs} + \epsilon_{ijt}^{rs} \quad (19)$$

$$\beta_1 \mathbf{LnT_{it}} = \begin{cases} \beta_1 LnTEBT_{ijt}^{rs} + \delta_1 \sum_{ij=1}^{n} W_{ij} LnTEBT_{ijt}^{rs} & Before \quad tax \\ \beta_1 LnTAX_t^{rs} + \beta_2 LnTEAT_{ijt}^{rs} + \beta_3 LnIPI_{ijt}^{rs} + & \\ \delta_1 \sum_{ij=1}^{n} W_{ij} LnTAX_t^{rs} + \delta_2 \sum_{ij=1}^{n} W_{ij} LnTEAT_{ijt}^{rs} + \delta_3 \sum_{ij=1}^{n} W_{ij} LnIPI_{ijt}^{rs} & After \quad tax \end{cases}$$

Where

- LnY_{ijt}^{rs} is the dependent variable and can take alternatively the values:
  - $LnEEE_{ijt}^{rs}$, the emissions embodied in exports of products of sector i from sector j and country r from county s in year t, and
  - $LnEEI_{ijt}^{rs}$ the emissions embodied in imports of product from sector i towards sector j and country r from county s in year t;
- $LnTAX_t^{rs}$ is carbon tax existing country r from county s in year t;
- $LnTEAT_{ijt}^{rs}$ is total emissions before tax in sector i, sector j and country r from county s and year t;
- $LnTEBT_{ijt}^{rs}$ is total emissions after tax of sector i in sector j including those arising from its trade and country r from county s in year t;

- $LnIPI_{ijt}^{rs}$ is the tax impact on industrial price index for industry i and sector j and country r from county s in year t;
- $LnGDP-engi_{t}^{rs}$ is GDP per unit of energy consumption country r from county s in year t;
- $LnClean-engi_{t}^{rs}$ is the ratio of clean energy to total energy use country r from county s in year t;
- $LnPGDP_{t}^{rs}$ is the GDP per capita country r from county s and year t;
- $LnIntermediate-Local_{ijt}^{rs}$ is intermediate inputs of sector i used/produced in local region of country j and country r from county s in year t;
- $LnFinal-Local_{ijt}^{rs}$ is the final demand for products of sector i in local region of country i andcountry r from county s in year t;
- $LnIntermediate-Other_{ijt}^{rs}$ is the intermediate inputs of sector i produced in other regions of country j and country r from county s in year t;
- $LnFinal-Other_{ijt}^{rs}$ is the final demand for products of sector i in other regions of country j and country r from county s in year t;
- $LnC-emission_{ijt}^{rs}$ is consumer carbon emissions in sector i in country j and country r from county s in year t;
- $LnP-emission_{ijt}^{rs}$ is producer emissions of sector i in country j and country r from county s in year t,
- with i and j = 1, ..., 56, for sectors, r and s = 1, ..., 43, for countries, and t = 1, ..., 15 for years,
- OECD, dummy variable equal to 1 if the country belong to the OECD, and 0 otherwise,

When it comes to the parameters:

- β_K, $K = 1, ..., 12$ is the parameter of interest to be estimated;
- λ is the spatial auto-regression coefficient;
- β_0 is the constant term;

- ϵ_{ijt} denotes an independent and identical distribution with zero mean and same variance;
- σ_0^2; U_{ijt} is the error term which captures all other omitted country factors, with $E(U_{ijt}) = 0$ for all i, j and t.

A spatial autoregressive term $\sum_{i=1}^{n} W_{t-1}^{rs} LnY_{ijt}^{rs}$ was included to estimate the spillover effects of carbon emissions of sector i and j embodied in trade for a given country r and s in year t.

Amidi & Majidi (2020) and Ho et al. (2013) used the bilateral trade flow in the last period to construct the time-varying spatial weights, $W_t = [W_{t-1}^{rs}]_{r,s=1}^{n}$. They also mention that the $(r, s)^{th}$ entry of the weight matrix W_t is the bilateral trade flow of country r and s at the year $t - 1$ (nominal millions of US dollar value).[14] W_t is row normalized, and the diagonal elements of W_t are all zero. A spatial matrix based on bilateral distances between the capital cities of each country is used to illustrate the spatial contiguity. To build this matrix, the matrices of $1/d_{ij}$ and $1/d_{ij}^2$ were created. Then, these matrices were divided by the summation of each horizontal row. Finally, when an element of the matrix is larger than the average of the matrix, number one is put in the cell, and in other cases, a zero is used in the cell. In the standard matrix, the final distance matrix is created where the sum of each horizontal row should equal one. The impact of tax on emissions embodied in trade is estimated with four matrices (inverse distance, inverse squared distance, EEBT, and geographical distance) is described below. The geographic and EEBT variables can be used to construct an instrument for emissions embodied in trade, which complicate our work.
Conspicuously, due to the simultaneity bias between explained and some explanatory variables,(distance and trade) the spatial econometric panel models could not be estimated by ordinary least squares (OLS). Consequently, the maximum likelihood (ML) was used to estimate the parameters of the spatial econometric models (Long et al., 2016).

3.6 Direct and indirect effects

In the matrix of partial derivatives of the dependent variable, if the dependent variable in certain situation changes (direct effect, every diagonal element of the matrix of partial derivatives), it

[14] In the spatial econometrics literature, the weight matrix is assumed to be exogenous to the dependent variable. Here, because LnY_{ijt} might affect the trade flow in year t, the trade flow was lagged for one period to form the weight matrices in order to avoid possible endogeneity problems.

will also lead to changes of the dependent variables in other situations (indirect effect, every off-diagonal element). Hence, direct and indirect effects are different for different situations in the sample (blindtextLeSage09 and Elhorst (2014)). For instance, due to the geographical distance, the effects of emissions embodied in exports on the host country (direct effect) are not the same as the neighboring country (indirect effect).

$$\begin{bmatrix} \frac{\partial E(Y)}{\partial x_{1k}} & \cdots & \frac{\partial E(Y)}{\partial x_{Nk}} \end{bmatrix}_t = (I - \delta W)^{-1}[\beta_{1k} I_N + \beta_{2k} W] \tag{20}$$

$$\begin{bmatrix} \frac{\partial E(Y)}{\partial x_{1k}} & \cdots & \frac{\partial E(Y)}{\partial x_{Nk}} \end{bmatrix} = [(1 - \tau)I - (\delta + \eta)W]^{-1}[\beta_{1k} I_N + \beta_{2k} W] \tag{21}$$

Equation 20, and equation 21 have displayed the mathematical formulas of the direct and indirect effects of a change in one of the explanatory variables on the dependent variable Y in the short term and the long term, respectively. In equation 20, indirect effects do not occur if we have $\delta = 0$ and $\beta_{2k} = 0$. In equation 21, indirect effects do not occur if we have $\delta = -\eta$ and $\beta_{2k} = 0$ (Elhorst, 2014).To measure the effect of emissions embodied in the trade before and after the taxation in the host country and neighbor countries, we calculate the direct and indirect effect of each exogenous variable in our study.

4 Results

4.0.1 Stationarity

The stationarity conditions show that a trade-off exists between the serial and spatial autocorrelation coefficients. In a spatial model, for achieving the stationarity, restrictions must be imposed on the parameters of the model and the spatial weights matrix W (Elhorst, 2014). Table 3 appendix A reports stationarity test results.

In the stationary test, hypothesis H_0 indicates that all panels have unit roots (nonstationary) and hypothesis H_1 indicates that at least one panel is stationary. The H_0 hypothesis is rejected at the 1% significance level when using a stationary test. As expected in Table 3, any particular amount of the proximity matrix w is in the range $(-1, +1)$, so all variables were stationary. After being sure about the stationary of all variables, the spatial econometric model is estimated.[15]

4.1 Spatial models

Based on the multi-regional input-output model, average emission embodied export and average emission embodied import, and average environmental tax can be obtained (see Table 5 in Appendix B). We then estimate SDM, SAR, SEM, and SAC models for each matrix. In Table 4 appendix A, the results of the Log-Likelihood Function test for selecting the best model are indicated. The results of the spatial recognition test (Log-Likelihood Function) demonstrates that zero hypotheses (lack of existence of spatial correlation) were rejected, and spatial auto-correlation in these four statuses existed. In other words, it indicates the presence of the spatial effects of this group of countries. According to the values of those tests, the SDM model was accepted.

When it comes to estimation results of models, in the Table 2 the dependent variable express emissions embodied in exports for status before and after the implementation of tax (columns (1) and (2), and (3) and (4), respectively). The spatial matrix in columns (1) and (3) is an inverse squared distance, in columns (2) and (4) is based on emission embodied in bilateral trade in the year of t-1.[16]

According to Table 2, the total emissions after-tax, final requirements in local region, carbon tax GDP per capita concerning distance have a positive, significant effect, and accepted sign while the ratio of clean energy to total energy use and OECD have a negative, significant effect and accepted sign on the emissions embodied in export when considering the situation after taxation. On one hand, considering the situation before taxation, the ratio of clean energy to total energy use for both matrices, have a negative, significant effect and accepted sign. Also, intermediate inputs in the local region, producer emissions, and OECD in distance matrix before tax have a negative, significant effect and accepted sign. On the other hand, in this situation, final requirements in the local region

[15] we check also spatial autocorrelation tests, serial autocorrelation tests, Heteroscedasticity tests, unit root tests, multicollinearity diagnostic tests for our models and variables.

[16] We made the estimation for inverse distance and distance and emissions embodied in bilateral trade as well. Results are available upon request.

in both matrix, GDP per capita intermediate inputs in the other region, final requirements in other regions, and consumer emissions in distance matrix have a positive, significant effect and accepted sign on the emissions embodied in export.

Moreover, the coefficient of the spatial auto-regression ρ was significant and positive, it indicates if the average weighted emissions embodied in exports of neighboring countries increases by one metric ton (Mt), on average, its emissions embodied in exports of the host country will increase by 8.2 (column 1), 0.3 (column 2), 8 (column 3) and 0.3 (column 4) percent [17] when we consider the effect of inverse squared distance, emissions embodied in bilateral trade and distance before and after-tax, respectively. The significance of these coefficients highlights the meaning of spatial correlation in the performance relation based on emissions embodied in export flows. It illustrates that countries that, one year, have emissions embodied in exports have on average the potential to grow even more the following year. Indirectly, spillover effects of the emissions embodied in exports of neighboring countries play an important role among these 43 countries.

The sign of the coefficient of the tax is positive and confirms the results of Elkins & Baker (2001). The coefficient of the variable TEAT shows that after-tax, the output and input prices of products grow, particularly for the energy products. Thus, some firms reduce the amount of investment; then, import goods can become more competitive, and imports will increase. The opposite holds for export which will fall. So the implementation of an emission tax causes an increase in the price level, an increment of total demand, and a reduction of the total supply. In short term, the country might witness a recession (Lu et al., 2010).

The ratio of clean energy to total energy use (Clean-engi) indicates high carbon emissions in production processes in line with the Coal-oil-gas-dominated fossil fuel mix, as found by Cao et al. (2019), Zhong et al. (2018), and Y. Jiang et al. (2015). The magnitude of carbon emissions embodied in trade is influenced by the level of GDP per capita (PGDP) during industrialization. Carbon emissions flow into high-income countries and flow out of poor countries, which confirmed the findings of L. Jiang et al. (2020), Honma & Yoshida (2020), Cao et al. (2019), Zhong et al. (2018), Grunewald et al. (2017), Zhong et al. (2015) Y. Jiang et al. (2015), Feng et al. (2014), and

[17] These figures are obtained as [exp(0.0823)-1]*100,[exp(0.00307)-1]*100, [exp(0.0798)-1]*100, and [exp(0.00318)-1]*100, respectively.

Xu & Dietzenbacher (2014).

Intermediate-local coefficient highlights that intermediate inputs contribute strongly to embodied carbon emissions: with a positive effect on emissions inflows, negative effect on carbon emissions outflows, as found by Zhong et al. (2018), Zhao, Wang, et al. (2016), and Xu & Dietzenbacher (2014). Final-Local has positive effects on emissions inflows, negative effects on carbon emissions outflows like in Zhong et al. (2018), and Xu & Dietzenbacher (2014). Intermediate-Other has a negative effect on emissions inflows and positive effect on carbon emissions outflows, as for Zhong et al. (2018), and Xu & Dietzenbacher (2014). The coefficient of the Final-Other has a positive impact on emissions inflows and outflows which confirms Zhong et al. (2018) and Xu & Dietzenbacher (2014).

Table 2: Estimation of Panel Spatial Models for Emissions Embodied in Exports Before and After Tax

VARIABLES	$1/d^2$	$EEBT$	$1/d^2$	$EEBT$
	Before Tax		After Tax	
Constant	-6.734***	-4.954***	-6.446***	-5.421***
	(0.823)	(1.336)	(0.762)	(1.211)
tax	-	-	0.0418**	0.0542**
	-	-	(0.0176)	(0.0246)
teat	-	-	0.117***	0.189***
	-	-	(0.0107)	(0.0161)
tebt	0.00843	-0.00323	-	-
	(0.00821)	(0.0133)	-	-
ipi	-	-	0.00589	0.0162
	-	-	(0.00748)	(0.0114)
GDP-engi	0.0474	0.0373	0.0238	0.00344
	(0.0598)	(0.0973)	(0.0542)	(0.0866)
Clean-engi	-0.0831***	-0.152***	-0.0918***	-0.169***
	(0.0236)	(0.0314)	(0.0214)	(0.0283)
pgdp	0.101**	0.0831	0.0787**	0.0661
	(0.0394)	(0.0533)	(0.0361)	(0.0488)
Intermediate-Local	-1.498**	-1.036	-0.275	-0.0965
	(0.602)	(0.875)	(0.576)	(0.798)
Final-Local	0.802***	0.764***	0.598***	0.619***
	(0.106)	(0.164)	(0.101)	(0.151)
Intermediate-Other	0.731*	0.228	-0.0979	-0.404
	(0.404)	(0.575)	(0.388)	(0.523)
Final-Other	0.620***	0.283	0.285	0.103
	(0.209)	(0.312)	(0.203)	(0.288)
C-emission	1.792***	1.181	0.565	0.190
	(0.654)	(0.942)	(0.625)	(0.858)
P-emission	-1.688***	-0.906	-0.477	-0.0221
	(0.652)	(0.935)	(0.625)	(0.852)
oecd	-0.301***	-0.0782	-0.415***	-0.211*
	(0.0939)	(0.118)	(0.0872)	(0.112)
w*tax	-	-	-0.00171	-0.00221
	-	-	(0.0111)	(0.00666)
w*teat	-	-	-0.00676***	-0.00119***
	-	-	(0.00181)	(0.000287)
w*tebt	-0.00227	-6.39e-05	-	-
	(0.00344)	(0.000506)	-	-
w*ipi	-	-	0.000605	3.68e-05
	-	-	(0.00323)	(0.000653)
w*GDP-engi	-0.0439***	0.00353	-0.0156	0.00239
	(0.0165)	(0.00295)	(0.0144)	(0.00291)
w*Clean-engi	0.0295***	0.00192	0.0229***	-0.000312
	(0.00855)	(0.00167)	(0.00870)	(0.00182)
w*pgdp	0.0279	0.00477	0.0582***	0.00364
	(0.0224)	(0.00532)	(0.0206)	(0.00479)
w*Intermediate-Local	-0.296	-0.152	-0.255	-0.382***
	(0.217)	(0.101)	(0.219)	(0.108)
w*Final-Local	-0.156***	0.0909**	-0.178***	0.138***
	(0.0559)	(0.0361)	(0.0516)	(0.0345)
w*Intermediate-Other	0.211	0.0345	0.212	0.158***
	(0.138)	(0.0557)	(0.140)	(0.0596)
w*Final-Other	0.159*	0.0206	0.136	0.0877***
	(0.0876)	(0.0290)	(0.0906)	(0.0311)
w*C-emission	0.441*	0.0655	0.421*	0.276***
	(0.246)	(0.0926)	(0.249)	(0.0981)
w*P-emission	-0.437*	-0.0543	-0.409	-0.262***
	(0.247)	(0.0938)	(0.251)	(0.0993)
w*oecd	-0.0970*	-0.148**	-0.129***	-0.193***
	(0.0521)	(0.0610)	(0.0479)	(0.0588)
ρ	**0.0823*** **	**0.00307*** **	**0.0798*** **	**0.00318*** **
	(0.00252)	(0.000521)	(0.00272)	(0.000523)
δ	0.523***	0.857***	0.479***	0.770***
	(0.0146)	(0.0239)	(0.0134)	(0.0214)

Source: Author's calculation. Note: *p<0.1; **p<0.05: ***p<0.01. w: weight matrix

The results of the Log-Likelihood Function test assert that zero hypotheses were rejected; there are spatial auto-correlations for these four specifications. Here again, the SDM model is accepted, as shown by the LR, the Moran, the Wald, and the LM test (Table 5 in appendix A).

In Table 3, for the specifications after-tax implementation, when the impacts of distance and trade are examined separately, the ratio of clean energy to total energy use has a significant negative influence. The coefficient of 0.1 for tax implies that emissions embodied in imports increase by 97.9 Mt when the tax rise by million dollars. The total emission after tax has a positive effect on emissions embodied in imports.

For the specifications before tax implementation, intermediate inputs in the local region, final requirements in the local region, consumer emissions, and OECD are always significant. Total emissions before tax, final demand requirements in other regions, and producer emissions are significant for the distance matrix only. The coefficient of spatial auto-regression ρ is significant and positive; if the average weighted emissions embodied in imports of neighboring countries increase by one Mt, then, in the host country, the emissions embodied in imports will increase by 5.8 (column 1), 0.3 (column 2), 5.4 (column 3), and 0.2 (column 4) percent [18], on average, when the effect of inverse squared distance, emissions embodied in bilateral trade and distance before and after-tax are, respectively, considered.

These coefficients are significant, which imply a spatial correlation in the performance relation based on emissions embodied in imports flow. It shows that at a certain period, countries that enjoy a year of emissions embodied in imports have on average the potential to grow even more the following year. Indirectly, spillover effects of emissions embodied in imports of neighboring countries play a crucial role. The IPI index represents the purchasing power losses for consumers after the implementation of the tax policy. It has a negative effect on emissions embodied in trade. The data of GDP-engi measures the efficiency of energy use. An increase in energy efficiency drives down the carbon emissions flows which confirmed (Zhong et al. (2018), Z.-M. Chen & Chen (2013), and Davis & Caldeira (2010)).

[18]These figures are obtained as [exp(0.0543)-1]*100,[exp(0.00242)-1]*100, [exp(0.0579)-1]*100, and [exp(0.00242)-1]*100 respectively.

Table 3: Estimation of Panel Spatial Models for Emissions Embodied in Imports Before and After Tax

VARIABLES	$1/d^2$	$EEBT$	$1/d^2$	$EEBT$
	After Tax		Before Tax	
Constant	-4.357**	1.973	-2.599*	1.793
	(1.780)	(1.701)	(1.402)	(1.445)
tax	-	-	0.0205	0.0979***
	-	-	(0.0317)	(0.0289)
teat	-	-	0.401***	0.299***
	-	-	(0.0206)	(0.0203)
tebt	0.0303*	-0.0233	-	-
	(0.0174)	(0.0168)	-	-
ipi	-	-	-0.0388***	0.00984
	-	-	(0.0141)	(0.0138)
GDP-engi	-0.123	-0.0614	-0.168*	-0.0449
	(0.128)	(0.124)	(0.0992)	(0.104)
Clean-engi	-0.0813	-0.115***	-0.0956**	-0.145***
	(0.0509)	(0.0400)	(0.0398)	(0.0339)
pgdp	0.351***	0.0679	0.255***	-0.00315
	(0.0916)	(0.0695)	(0.0719)	(0.0596)
Intermediate-Local	-5.712***	-2.145*	-2.965***	-0.170
	(1.318)	(1.122)	(1.080)	(0.968)
Final-Local	1.416***	0.379*	0.624***	-0.00531
	(0.227)	(0.210)	(0.193)	(0.185)
Intermediate-Other	3.365***	1.204	1.587**	0.0400
	(0.884)	(0.736)	(0.722)	(0.631)
Final-Other	1.289***	0.214	0.754*	-0.254
	(0.461)	(0.405)	(0.385)	(0.356)
C-emission	4.918***	1.993*	2.426**	0.0572
	(1.434)	(1.209)	(1.173)	(1.044)
P-emission	-4.958***	-1.802	-2.528**	-0.0196
	(1.429)	(1.200)	(1.171)	(1.037)
oecd	-0.671***	-0.560***	-0.704***	-0.570***
	(0.216)	(0.161)	(0.169)	(0.141)
w*tax	-	-	0.00636	-0.0113
	-	-	(0.0200)	(0.00758)
w*teat	-	-	-0.0228***	-0.000666**
	-	-	(0.00330)	(0.000333)
w*tebt	-0.0189**	0.000540	-	-
	(0.00739)	(0.000619)	-	-
w1*ipi	-	-	0.00979*	0.000566
	-	-	(0.00589)	(0.000749)
w*GDP-engi	-0.128***	-0.000609	0.00781	-0.000412
	(0.0364)	(0.00361)	(0.0268)	(0.00334)
w*Clean-engi	0.0186	0.00247	0.0149	0.000702
	(0.0188)	(0.00206)	(0.0159)	(0.00209)
w*pgdp	-0.185***	0.000605	-0.0400	-0.00192
	(0.0493)	(0.00663)	(0.0391)	(0.00562)
w*Intermediate-Local	1.186**	0.144	1.576***	-0.0313
	(0.461)	(0.123)	(0.401)	(0.123)
w*Final-Local	0.359***	-0.0135	0.0556	0.0161
	(0.119)	(0.0443)	(0.0937)	(0.0399)
w*Intermediate-Other	-1.047***	-0.0992	-1.055***	0.00717
	(0.293)	(0.0675)	(0.256)	(0.0678)
w*Final-Other	-0.440**	-0.0499	-0.587***	0.00493
	(0.187)	(0.0351)	(0.167)	(0.0354)
w*C-emission	-1.710***	-0.148	-1.786***	0.0339
	(0.524)	(0.112)	(0.460)	(0.112)
w*P-emission	1.658***	0.162	1.780***	-0.0175
	(0.525)	(0.113)	(0.462)	(0.113)
w*oecd	0.211*	-0.197***	0.0264	-0.227***
	(0.116)	(0.0729)	(0.0914)	(0.0664)
ρ	**0.0579*** **	**0.00301*** **	**0.0543*** **	**0.00242*** **
	(0.00457)	(0.000828)	(0.00427)	(0.000774)
δ	1.078***	1.048***	0.843***	0.886***
	(0.0312)	(0.0303)	(0.0244)	(0.0256)

Source: Author's calculation. Note: *p<0.1; **p<0.05: ***p<0.01. w: weight matrix

4.2 Direct, Indirect, and Total Effect by Countries

According to Table 4, in both before and after-tax models, the ratio of clean energy to total energy use has negative effects on emissions embodied in exports for direct, indirect (spillover), and total effect; an increase in this ratio of 1% in given country results in a decrease of 0.02 and 0.01 of emissions embodied in exports in all countries, respectively, before and after-tax. Additionally, in both models, for specification of direct, indirect (spillover), and total effect. When considering the impact of emissions embodied in exports, 1% increase in the GDP per unit of energy consumption, in per capita GDP, final demand in the local region, and final demands in other regions, derive to 3.1, 2.2, 70.3, and 5.2 percent, in before tax specification, and 0.95, 1.3, 60.8 and 5.8, in the after-tax model, increase in this variable in all 43 countries at year t+1, respectively.

Moreover, the direct effect, indirect effect (spillover), and the total effect of the intermediate inputs in the local region and producer emissions after-tax are positive while they are being negative, before tax. An increase of 1% of the intermediate inputs in the local region, and the producer emissions lead to a decrease of 6.8 and 7.4 percent, before tax, and an increase in 6.2 and 0.5 percent, after-tax, in this variable in all 43 countries at year t+1, respectively.

We also show that an increase of 1% in the intermediate inputs for other regions and consumer emissions cause an increase in 2.85 and 6.58 percent, before tax, and a decrease in 5.98 and 2.36 percent, after-tax, in this variable in all 43 countries at year t+1, respectively. Also, the direct effect, indirect effect (spillover), and the total effect of the carbon tax in both models have a positive effect, while the tax impact on price index (IPI) has a negative effect on emissions embodied in exports.

Table 4: Direct and Indirect Effects of the SDM Model for Emissions Embodied in exports

Variables	Beta	Total	Direct	InDirect	Beta	Total	Direct	InDirect
	Before Tax				After Tax			
tax	-	-	-	-	0.0017	0.0012	0.0001	0.0011
teat	-	-	-	-	0.0492	0.0359	0.0029	0.033
tebt	0.0053	0.004	0.0003	0.0036	-	-	-	-
ipi	-	-	-	-	-0.0017	-0.0013	-0.0001	-0.0012
GDP-engi	0.0423	**0.0318**	0.0028	0.029	0.013	**0.0095**	0.0008	0.0087
Clean-engi	-0.0151	-0.0113	-0.001	-0.0104	-0.028	-0.0205	-0.0016	-0.0188
pgdp	0.0293	**0.0221**	0.0019	0.0201	0.0174	**0.0127**	0.001	0.0116
Intermediate-Local	-0.0899	**-0.0677**	-0.0059	-0.0618	0.0848	**0.0618**	0.005	0.0568
Final-Local	0.9331	**0.7025**	0.0613	0.6412	0.8341	**0.6084**	0.049	0.5594
Intermediate-Other	0.0378	**0.0285**	0.0025	0.026	-0.082	**-0.0598**	-0.0048	-0.055
Final-Other	0.0695	**0.0523**	0.0046	0.0477	0.0795	**0.058**	0.0047	0.0533
C-emission	0.0874	**0.0658**	0.0057	0.0601	-0.0323	**-0.0236**	-0.0019	-0.0217
P-emission	-0.0978	**-0.0736**	-0.0064	-0.0672	0.0066	**0.0048**	0.0004	0.0045
oecd	-0.0869	-0.0655	-0.0057	-0.0597	-0.0928	-0.0677	-0.0055	-0.0622

Source: Author's calculation

According to Table 5 and impact of emissions embodied in imports, if we 1% increase the per capita GDP, intermediate inputs in other regions, final demands in other regions and consumer emissions derive to a decrease of 2.7, 100, 145 and 295 percent, before tax, and 6.8, 129, 113 and 289 percent, after-tax, in this variable in all 43 countries at year t+1, respectively.

An increase in the ratio of clean energy to total energy use, intermediate inputs in the local region, final demand in the local region, and producer emissions in other regions lead to an increase in 16.69, 222, 72.43, and 295, before tax, and an increase in 7.34, 245, 14.08 and 285 percent, after-tax, in this variable in all 43 countries at year t+1, respectively. An increase in 1% GDP per unit of energy consumption causes an increase in 6.88, before tax, and a decrease in 6.74, after-tax, in this variable in all 43 countries at year t+1. Finally, the carbon tax and total emissions in the model after-tax and total emissions in the model before tax have positive effects, while the tax impact on the price index has a negative effect on emissions embodied in imports.

Table 5: Direct and Indirect Effects of the SDM Model for Emissions Embodied in Imports

Variables	Beta	Total	Direct	InDirect	Beta	Total	Direct	InDirect
	Before Tax				After Tax			
tax	-	-	-	-	0.0096	0.0088	0.0019	0.0069
teat	-	-	-	-	0.3321	0.3059	0.0663	0.2395
tebt	0.0646	0.0596	0.0131	0.0465	-	-	-	-
ipi	-	-	-	-	-0.015	-0.0138	-0.003	-0.0108
GDP-engi	0.0746	**0.0688**	0.0151	0.0537	-0.0732	**-0.0674**	-0.0146	-0.0528
Clean-engi	0.1809	**0.1669**	0.0367	0.1303	0.0797	**0.0734**	0.0159	0.0575
pgdp	-0.0295	**-0.0272**	-0.006	-0.0213	-0.0747	**-0.0688**	-0.0149	-0.0539
Intermediate-Local	2.4115	**2.2248**	0.4887	1.736	2.6563	**2.4468**	0.5307	1.9161
Final-Local	0.7851	**0.7243**	0.1591	0.5652	0.1529	**0.1408**	0.0305	0.1103
Intermediate-Other	-1.0872	**-1.003**	-0.2203	-0.7826	-1.3974	**-1.2872**	-0.2792	-1.008
Final-Other	-1.5743	**-1.4524**	-0.3191	-1.1333	-1.2321	**-1.135**	-0.2462	-0.8888
C-emission	-3.1963	**-2.9488**	-0.6478	-2.301	-3.141	**-2.8933**	-0.6276	-2.2658
P-emission	3.198	**2.9504**	0.6481	2.3022	3.0964	**2.8522**	0.6186	2.2335
oecd	0.621	0.5729	0.1259	0.4471	0.5247	0.4833	0.1048	0.3785

Source: Author's calculation

5 Conclusions

Studies such as this one, on the spatial economics model, for emissions embodied in the trade when there is a carbon tax had been overlooked in the previous literature. Thus our research focuses on providing a preliminary exploration for analysis of emissions embodied in the trade before and after carbon tax. To account for intermediate inputs and final demands for imports and exports, we match the emissions data to WIOD for 43 countries' input-output tables and construct total domestic emissions intensities for each sector in the period 2000-2014. As a result, at the sector level, the highest direct, total, and indirect emission of CO_2 comes from the category [Electricity and heat production], while the lowest indirect and complete emissions of CO_2 occurs in the category [Other sectors]. For several measures of direct emissions of CO_2, the category [Residential buildings, commercial and public services] appears as the lowest pollutant activity.

In this study, the consequences of introducing a full border tax adjustment were scrutinized. We focus on carbon taxation and its impact on international carbon emissions reduction, via an increase in the price of carbon. The rise in price leads to an adjustment in the quantity of CO_2 emitted in exports and imports (Tables 2 and 3). We highlight the existence of a spillover effect of emissions embodied in exports and imports by considering the distance and trade matrix before and after tax.

According to the distance matrix, when we increase the carbon tax by one million dollars, pollution by import in Mt increases by 2 percent [19]. Also, when we increase the carbon tax by one million dollars, pollution by import in Mt is increases by 9.8 percent [20], taking into account the trade matrix (comparative advantage). Moreover, the spillover effect of emissions embodied in imports reflected with distance and trade matrices in situations after-tax (5.43 and 0.2 percent, respectively) diffused less pollution in neighboring countries than before tax (5.79 and 0.3 percent, respectively). In other words, tax implementation has been effective in emission embodied in import with trade matrix, but this effect is less tangible when considering the geographical distance matrix.

According to the distance matrix, when we increase the carbon tax by one million dollars, pollution by export in Mt is increases by4 percent [21]. Moreover, when we increase the carbon tax by one million dollars, pollution by export in Mt increases by 5.4 percent [22], taking into account the comparative advantage situation. Hence, when competitive advantage is considered, the taxation on export emission increases the pollutant in the proximity area (0.32 percent), while, before taxation, it was 0.31 percent. Also, taking into account the distance matrix, if we increase one Mt of emission embodied in export in one country, emission embodied in the export of neighboring countries increase by 8.2 and 7.9 percent, in the situation before and after-tax, respectively. So, the outcomes are highly sensitive to the choice of trade or distance as the weight matrix. In other words, tax implementation has been effective in reducing emission embodied in export with the weight matrix of geographical distance, but this effect is less tangible when trade is considered as the weight matrix.

These results suggest that when the effects of trade and taxation have been considered in global climate policy, all countries should endure greater emissions reduction responsibility and increase the production of low carbon goods more than that of other goods. Considering the large amount of emission embodied in export by the investigated countries, we suggest first reduce the export flow of local high energy-consuming products. This target can be achieved by raising their prices or reducing the capacity of heavy industry or increasing the taxation of products. These countries/regions should also further increase the flow of import of high energy-consuming products, to reduce local energy consumption while strengthening economic ties with the neighboring countries. Moreover,

[19] These figures are obtained as [exp(0.0205)-1]*100.
[20] These figures are obtained as [exp(0.0979)-1]*100.
[21] These figures are obtained as [exp(0.0418)-1]*100.
[22] These figures are obtained as [exp(0.0542)-1]*100.

governments set the overall tax policy for the world to try to reduce the considerable energy consumption and the excessively high percentage of heavy industry. insofar as a high carbon tax rate leads to a considerable disadvantageous impact on the economy and some activity sectors probably experience extremely negative effects, the solution should be to start with a low tax rate.

6 Policy Recommendations

1. Most of the pollution is related to the electricity category. Taking this into account the policymaker should be taking a persuasive and precise policy suitable for providing fewer emissions in sectors where emissions are more authorized or have higher expected levels. Restricting carbon emissions by global rules and taxes of the worldwide community will reduce more pollution than the different decisions of each government, coordination is crucial, special when cooperation is not easy to find ((Barrett, 2016)).

2. EU zone or other integrated zones should harmonize there taxes on order to avoid increase emissions. Nations rely on two-sided and multilateral accords where nations interconnect their trading systems by accepting allowances or credits of each other. The linkage might generate cost savings and market liquidity advantages for all linked systems while reducing the greenhouse gas emissions overall equally. The linking agreements might also offer nations using tools for coordinating and harmonizing their emission restrictions, pricing inspections, and other elements. By promoting systems to cooperate through decentralized agreements, a centralized climate accord may in principle be replaced by a connection. As far as the need to coordinate worldwide reductions of emissions is concerned, and in particular international emissions, it is very necessary to emphasize that, opposed to harmonization of fuel taxes, emissions trading can easily be adopted in the transport sector. The emissions trading scheme seems as though from a European – and the political economy – standpoint like an obvious and particularly desirable scheme for organizing emissions control, particularly when it comes to the transnational dimension of that activity. This should be the framework under which emissions policies are harmonized with other areas worldwide, some of which are presently debating their carbon trading plans.

3. There is the spillover effect before and after taxation. So, the government should care about their decisions on environmental taxation in there country and their neighbors. Developing countries produce goods that are consumed by other countries, but carbon emissions are charged to their national accounts. So, a country may clean up its own backyard while throwing the rubbish to their neighbors (Q. Wang & Yang (2020); Duan et al. (2018); Z. Zhang, Zhu, & Hewings (2017); Su & Ang (2014); Carvalho et al. (2013)). So, in the end, the price for consumers is higher (and can even become prohibitive) in countries consuming imported goods and services than in the countries producing and exporting those goods and services. The tendency to make low-carbon goods is also higher in the latter countries than in the former. The best strategy for controlling emissions would be to impose the same carbon tax in all the countries which produce such goods and services. In this case, the final cost of producing good in the neighboring country will be higher than the host country (If a company wants to produce goods in a neighboring country, in addition to the fixed carbon tax price, it also has to pay a fixed and variable cost of producing the goods.).

4. converging to the same tax price will be beneficial to the all countries of regions. More critically, the implementation of an international carbon tax on both production and consumption can be a solution, for two reasons:

    (a) Countries that did not have emission tax are progressively starting to propose and implement such ideas. Then, a common international tax would strengthen mutual collaborations (Ren et al., 2020).

    (b) Countries producing more carbon than others, tend to be more reluctant to impose emissions prices at the same level as the other fewer pollutant countries. If none of the countries accept the carbon tax law and they go on polluting, the transmission of pollution to neighboring countries through trade or construction will increase pollution at the global level. The whole world will end up paying a much higher price than taxes paid by each country.

5. Carbon tax reduced emission embodied in export and import from the host country to neighboring countries, taking into account the distance matrix. So, our policy recommendation to

governments should be not to stop the carbon tax but to care about their effect on neighboring countries. The tax had the expected effect nevertheless, we should be cautious when analyzing also the comparative advantage of the countries because this could have an effect increasing EEE after taxes due to dirty specializations.

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A Appendix

A

Table 1: The summary of Literature review

Author(s)	Statistical population	Study period	Variable of interest	Method used	Database used	result
(Zhong et al., 2018)	39 countries (27 EU, 12 other countries)	1995-2011	EEI, EEE, GDP-engi, Clean-engi, PGDP, Iiin, Final-Local, IIex, Final-Other	MRIO and Spatial econometrics	WIOD	GDP-engi: negative, Clean-engi: negative, PGDP: positive, Iiin: positive, Final-Local: positive, Iiex: negative, Final-Other: negative and positive
(Q. Wang & Zhou, 2019b)	Germany-US	2000-2015	decomposition on five driving forces and EET, EC, GDP	MRIO and SDA	EORA	GDP: positive
(da Silva Freitas et al., 2016)	Brazil	2009	GDP, IPI	SAM and CGE model	Brazilian IO and SUT, IBGE	GDP: negative
(J. Guo et al., 2018)	China	2000-2015	direct carbon emission, EEE	IO model	China's IO	direct carbon emission: negative, EEE: positive
(Zhong et al., 2015)	China's provincial	2007	EEI, EEE, BEET, P-emission, C-emission, GDP	MRIO	China's IO	GDP: positive, P-emission: positive, C-emission: positive
(Honma & Yoshida, 2020)	40 countries	1988-2008	GDPPC	BEET	WIOD	GDPPC: negative
(L. Jiang et al., 2020)	39 countries	1995-2011	GDP	MRIO and LMDI	WIOD	GDP: positive
(Mizgajski, 2013)	Poland	2004	EEE,EEI	IO model	GTAP	negative trade balance
(Fernández-Amador et al., 2016)	78 regions	1997-2011	P-emission, C-emission, EEE, EEI	MRIO	GTAP	P-emission: positive, C-emission: positive
(L. Wu & Wang, 2017)	China	2002, 2007 and 2010	Intermediate-Other, Final-Other, Final-Local, Intermediate-Local	MRIO	EEPT	The sign of the variables changes according to the regions
(Makarov & Sokolova, 2015)	Russia	1995	EEE, EEI, P-emission, C-emission	MRIO	WIOD	P-emission: positive, C-emission: positive
(Su & Ang, 2014)	China	1997	GDP	EEBT and MRIO	China's regional IO	GDP: positive
(Q. Wang & Zhou, 2019a)	US-Japan	2000 -2011	P-emission, C-emission, EEBT, GDP	MRIO and SDA	WIOD	GDP: positive, P-emission: positive, C-emission: positive
(Q. Wang et al., 2019)	China-German	1995-2009	Intermediate-Other, Final-Other, Final-Local, Intermediate-Local	SRIO and SDA	WIOD	The sign of the variables changes according to the sectors
(Long et al., 2018)	China and Japan	2000-2014	EEE, EEI, P-emission, C-emission	MRIO	WIOD	P-emission: positive, C-emission: positive
(Elliott et al., 2010)	US	2004	P-emission, C-emission	CGE model	GTAP	P-emission: positive, C-emission: positive
(Elkins & Baker, 2001)	Denmark	2008-2012	tax	CGE model	OECD	tax: positive
(S. Wang et al., 2020)	China	2004-2011	GDP	EEBT and SDA	GTAP	GDP: positive
(Du et al., 2011)	China–US	2002–2007	EEI, EEE, Intermediate-Other, Intermediate-Local	SDA	China's National Bureau of Statistics and China Statistical Yearbook	EEI: negative, EEE: positive, Intermediate-Local and Intermediate-Other: positive
(Cao et al., 2019)	China	2017–2030	GDP, Consumption/GDP, GDP per capita	national carbon emission trading system	China's IO table and National Accounts	GDP: negative
(S. Wang et al., 2019)	China and Australia	2000-2014	GDP	EEBT	WIOD	GDP: positive
(Grunewald et al., 2017)	158 countries	1980-2008	GDP per capita	OLS and group fixed effects model	SWIID	below a certain level of GDP per capita
we	43 countries	2000-2014	EEE, EEI, TAX, TEBT, TEAT, IPI, GDP-engi, Clean-engi, PGDP, Intermediate-Local, Final-Local, Intermediate-Other, Final-Other, C-emission,P-emission	SDA, MRIO and Spatial econometrics	WIOD	Tax: positive, GDP-engi: negative, Clean-engi: negative, PGDP: positive, IIin: positive, Final-Local: positive, IIex: negative, Final-Other, P-emission: positive, C-emission: positive

Table 2: Average of Share of Direct, Indirect and total Carbon Emission in 5 categories in period 2000-2014

categories	Avrg. SDIE	Avrg. SDE	Avrg. SIE
Transport (%)	20	26.7148	20.13163
Electricity and heat production (%)	20.05237	40.93134	20.14753
Manufacturing industries & construction (%)	20.01013	7.110258	20.08294
Other sectors (%)	19.95103	14.66082	19.98918
Residential buildings & commercial and public services (%)	19.94718	10.58278	19.96783

source: Author's calculation

Avrg. SDIE: Average share of direct and indirect emission, Avrg. SDE: Average share of direct emission, Avrg. SIE:Average share of indirect emission

Table 3: Results of Stationary Test

	DF		ADF		APP	
	Dickey-Fuller Test		Augmented Dickey-Fuller Test		Augmented Phillips-Perron Test	
	No Trend	Trend	No Trend	Trend	No Trend	Trend
Before and After tax EEE for all four matrix ($1/d$, $1/d^2$, $EEBT$ and $distance \times EEBT$)	- 17.4734***	- 17.2467***	-8.8981***	- 14.2286***	- 17.5795***	- 17.8935***
Before and After tax EEI for all four matrix ($1/d$, $1/d^2$, $EEBT$ and $distance \times EEBT$)	- 17.2596***	-17.772***	-9.1796***	- 17.3941***	- 17.3275***	- 18.7254***

source: Author's calculation

Table 4: Results of Selection Model Tests for Emissions Embodied in Exports Before and After Tax

			SDM	SAC	SEM	SAR
After Tax	Log Likelihood Function	$1/d^2$	**-455.908**	-501.745	-501.071	-695.792
		$EEBT$	**-746.597**	-766.162	-774.967	-793.501
Before Tax	Log Likelihood Function	$1/d^2$	**-514.411**	-547.417	-553.264	-780.331
		$EEBT$	**-815.793**	-835.839	-877.358	-869.983
After Tax	LR Test	$1/d^2$	858.6497 ***	399.7964 ***	**1296.0179*** **	251.9009***
		$EEBT$	36.9630***	53.1820***	**72.6409*** **	16.3346***
Before Tax	LR Test	$1/d^2$	1069.4587 ***	11.9344 ***	**1376.8246*** **	237.8938***
		$EEBT$	**34.6413*** **	0.0019 ***	6.7194 ***	22.2970***
After Tax	LM Error (Burridge)	$1/d^2$	1835.3325***	2285.3894 ***	2285.3894***	2285.3894***
		$EEBT$	55.0979***	429.4411 ***	429.4411***	429.4411***
Before Tax	LM Error (Burridge)	$1/d^2$	2080.2515 ***	2600.1593 ***	2600.1593***	2600.1593***
		$EEBT$	55.1978 ***	505.2714***	505.2714***	505.2714***
After Tax	LM Error (Robust)	$1/d^2$	85.8318 ***	682.2846***	682.2846***	682.2846***
		$EEBT$	13.3914***	156.6260 ***	156.6260 ***	156.6260***
Before Tax	LM Error (Robust)	$1/d^2$	4.97e+04 ***	1.50e+05 *	1.50e+05*	1.50e+05*
		$EEBT$	231.4984***	2.36e+04**	2.36e+04 **	2.36e+04**
After Tax	LM Lag (Anselin)	$1/d^2$	1764.9363 ***	3728.4581***	3728.4581***	3728.4581***
		$EEBT$	43.5225***	304.3896 ***	304.3896***	304.3896***
Before Tax	LM Lag (Anselin)	$1/d^2$	2225.5606 ***	3444.2500***	3444.2500 ***	3444.2500***
		$EEBT$	46.6183 ***	379.6509***	379.6509 ***	379.6509***
After Tax	LM Lag (Robust)	$1/d^2$	15.4356 ***	2125.3533 ***	2125.3533 ***	2125.3533***
		$EEBT$	1.8159 *	31.5745 ***	31.5745 ***	31.5745***
Before Tax	LM Lag (Robust)	$1/d^2$	4.98e+04 ***	1.51e+05 *	1.51e+05*	1.51e+05*
		$EEBT$	222.9190***	2.34e+04 **	2.34e+04**	2.34e+04**
After Tax	AIC[23]	$1/d^2$	969.8165	1033.489	1034.143	1423.584
		$EEBT$	1551.194	1566.325	1581.934	1619.001
Before Tax	AIC	$1/d^2$	1078.823	1124.834	1134.528	1588.663
		$EEBT$	1681.586	1701.678	1780.716	1767.966
After Tax	BIC [24]	$1/d^2$	1099.425	1100.528	1105.651	1495.092
		$EEBT$	1680.802	1642.302	1653.442	1690.509
Before Tax	BIC	$1/d^2$	1190.554	1191.873	1197.098	1651.232
		$EEBT$	1793.318	1768.717	1838.817	1830.536
After Tax	Degrees of freedom	$1/d^2$	29	15	16	16
	Degrees of freedom	$EEBT$	29	17	16	16
Before Tax	Degrees of freedom	$1/d^2$	25	15	14	14
	Degrees of freedom	$EEBT$	25	15	13	14

Source: Author's calculation. Note: *, **, and *** denote significance at 10%, 5%, and 1% level. The numbers in the () are the t–statistic.

Table 5: Results of Selection Model Tests for Emissions Embodied in Imports Before and After Tax

			SDM	SAC	SEM	SAR
After Tax	Log Likelihood Function	$1/d^2$	**-753.616**	-792.134	-793.743	-855.965
		$EEBT$	**-777.319**	-857.121	-859.943	-870.987
Before Tax	Log Likelihood Function	$1/d^2$	**-902.163**	-965.4405	-967.678	-1003.35
		$EEBT$	**-878.168**	-1031.13	-986.481	-1026.89
After Tax	LR Test	$1/d^2$	162.1024***	2.7493**	**210.8688*** **	45.1557***
		$EEBT$	9.7860***	6.5061***	**31.6680*** **	13.3546***
Before Tax	LR Test	$1/d^2$	159.9940***	4.4183***	**187.0732*** **	77.6447***
		$EEBT$	13.2280***	4.2578***	**118.0840*** **	25.1705***
After Tax	LM Error (Burridge)	$1/d^2$	430.8375***	620.2473***	620.2473***	620.2473***
		$EEBT$	6.4993***	106.5023***	106.5023***	106.5023***
Before Tax	LM Error (Burridge)	$1/d^2$	317.4636***	352.4611***	352.4611***	352.4611***
		$EEBT$	6.8341***	176.4571***	176.4571***	176.4571***
After Tax	LM Error (Robust)	$1/d^2$	321.6487***	921.3551***	921.3551***	921.3551***
		$EEBT$	2.8341**	0.7122	0.7122	0.7122
Before Tax	LM Error (Robust)	$1/d^2$	38.5859***	36.3757***	36.3757***	36.3757***
		$EEBT$	4.3674***	9.4530***	9.4530***	9.4530***
After Tax	LM Lag (Anselin)	$1/d^2$	470.2623***	406.8592***	406.8592***	406.8592***
		$EEBT$	4.0149***	111.1076***	111.1076***	111.1076***
Before Tax	LM Lag (Anselin)	$1/d^2$	331.8253***	376.5123***	376.5123***	376.5123***
		$EEBT$	4.6548***	195.7482***	195.7482***	195.7482***
After Tax	LM Lag (Robust)	$1/d^2$	361.0735***	707.9670***	707.9670***	707.9670***
		$EEBT$	0.3497	5.3175***	5.3175***	5.3175***
Before Tax	LM Lag (Robust)	$1/d^2$	52.9475***	60.4269***	60.4269***	60.4269***
		$EEBT$	2.1881**	28.7441***	28.7441***	28.7441***
After Tax	AIC[25]	$1/d^2$	1565.232	1618.268	1619.485	1743.929
		$EEBT$	1612.637	1748.241	1751.886	1773.974
Before Tax	AIC	$1/d^2$	1854.327	1960.881	1963.355	2034.695
		$EEBT$	1806.335	2090.252	2000.962	2081.779
After Tax	BIC [26]	$1/d^2$	1694.84	1694.246	1690.993	1815.437
		$EEBT$	1742.245	1824.219	1823.394	1845.482
Before Tax	BIC	$1/d^2$	1966.058	2027.92	2025.925	2097.265
		$EEBT$	1918.066	2152.821	2063.532	2144.348
After Tax	Degrees of freedom	$1/d^2$	29	17	16	16
	Degrees of freedom	$EEBT$	29	17	16	16
Before Tax	Degrees of freedom	$1/d^2$	25	15	14	14
	Degrees of freedom	$EEBT$	25	14	14	14

Source: Author's calculation. Note: *, **, and *** denote significance at 10%, 5%, and 1% level. The numbers in the () are the t–statistic.

B

Table 1: Section divisions based on ISIC code

	Transport (%)		Electricity and heat production (%)		Manufacturing industries and construction (%)		Other sectors (%)		Residential buildings and commercial and public services (%)
G45	Wholesale and retail trade and repair of motor vehicles and motorcycles	C33	Repair and installation of machinery and equipment	C10-C12	Manufacture of food products, beverages and tobacco products	A01	Crop and animal production, hunting and related service activities	J61	Telecommunications
G46	Wholesale trade, except of motor vehicles and motorcycles	D35	Electricity, gas, steam and air conditioning supply	C13-C15	Manufacture of textiles, wearing apparel and leather products	A02	Forestry and logging	J62_J63	Computer programming, consultancy and related activities; information service activities
G47	Retail trade, except of motor vehicles and motorcycles	E36	Water collection, treatment and supply	C16	Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials	A03	Fishing and aquaculture	K65	Insurance, reinsurance and pension funding, except compulsory social security
H49	Land transport and transport via pipelines			C17	Manufacture of paper and paper products	B	Mining and quarrying	K66	Activities auxiliary to financial services and insurance activities
H50	Water transport			C18	Printing and reproduction of recorded media	E37-E39	Sewerage; waste collection, treatment and disposal activities; materials recovery; remediation activities and other waste management services	N	Administrative and support service activities
H51	Air transport			C19	Manufacture of coke and refined petroleum products	H53	Postal and courier activities	O84	Public administration and defence; compulsory social security
H52	Warehousing and support activities for transportation			C20	Manufacture of chemicals and chemical products	I	Accommodation and food service activities	P85	Education
				C21	Manufacture of basic pharmaceutical products and pharmaceutical preparations	J58	Publishing activities	Q	Human health and social work activities
				C22	Manufacture of rubber and plastic products	J59_J60	Motion picture, video and television programme production, sound recording and music publishing activities; programming and broadcasting activities	R_S	Other service activities
				C23	Manufacture of other non-metallic mineral products	K64	Financial service activities, except insurance and pension funding	T	Activities of households as employers; undifferentiated goods- and services-producing activities of households for own use
				C24	Manufacture of basic metals	L68	Real estate activities	U	Activities of extraterritorial organizations and bodies
				C25	Manufacture of fabricated metal products, except machinery and equipment	M69_M70	Legal and accounting activities; activities of head offices; management consultancy activities		
				C26	Manufacture of computer, electronic and optical products	M71	Architectural and engineering activities; technical testing and analysis		
				C27	Manufacture of electrical equipment	M72	Scientific research and development		
				C28	Manufacture of machinery and equipment n.e.c.	M73	Advertising and market research		
				C29	Manufacture of motor vehicles, trailers and semi-trailers	M74_M75	Other professional, scientific and technical activities; veterinary activities		
				C30	Manufacture of other transport equipment				
				C31_C32	Manufacture of furniture; other manufacturing				
				F	Construction				

Table 2: Source of Variables

Short name of Variable	Full Name	Definition	Source
EEE	Emissions embodied in exports		WIOD
EEI	Emissions embodied in imports		WIOD
TAX	Carbon tax	Carbon taxation tries to replace trading as the international system of carbon emissions reduction	OECD
TEBT	Total emissions before tax		WIOD
TEAT	Total emissions after tax	After emission tax is inflicted, the output and input prices of products, particularly energy sector products, will grow	WIOD
IPI	The tax impact on price index	Implementation of the tax policy could be measured by a general price index that explain the purchasing power losses for consumers	WIOD
GDP-engi	GDP per unit of energy consumption	Unit of energy consumed to generate the amount of GDP in a country	World Bank
Clean-engi	The ratio of clean energy to total energy use	Coal-oil-gas-dominated fossil fuel mix produces a lot of carbon emission in production processes	World Bank
PGDP	Per capita GDP	global trade expands, rapid economic growth is stimulating to speed up global industrial transfer, and thus is influencing carbon emissions embodied in trade all over the world	World Bank
Intermediate-Local	Intermediate inputs in local region	In international trade, foreign capital and energy inflows are the main sources of intermediate inputs, and thus affect carbon emissions flows	WIOD
Final-Local	Final requirements in local region	For one country, each sector in this country would import other regions' final goods and services as final requirements to meet the needs of the local region through international supply chains in the process of globalization	WIOD
Intermediate-Other	Intermediate inputs in other regions		WIOD
Final-Other	Final requirements in other regions		WIOD
C-emission	Consumer Emissions	Carbon dioxide emissions calculated from the consumer perspective are significantly higher than producer emission	WIOD
P-emission	Producer Emissions	Carbon dioxide emissions calculated from the producer	WIOD

Table 3: The abbreviated name

SDA: structural decomposition analysis	NBER: National Bureau of Economic Research
WIOT: input-output tables semi-closed model with eight household groups	FGLS: Feasible Generalized Least Squares
SNA: System of National Accounts	CAS: Chinese Academy of Sciences
SUT: Supply and Use Tables	CEAD: China Emissions Accounts and Datasets
SAM: Social Accounting Matrix	AGEIS: Australian Greenhouse Emissions Information System
SRIO: single region input-output tables	FTA: free trade agreement
BTIO: bilateral trade input-output model	CGER: Center for Global Environmental Research and NIES: National Institute for Environmental Studies
NEEBT: net CO_2 emissions embodied in bilateral trade	SWIID: Standardized World Income Inequality Database
TEAM: Trade and Environmental Assessment Model	BEA: Bureau of Economic Analysis
LMDI: Logarithmic Mean Divisia Index	NBS: Chinese National Bureau of Statistics
BEETI: net balance of emissions embodied in trade in intermediates and BEETT: total trade	IBGE: Brazilian Institute of Geography and Statistics
	GTAP: Global Trade Analysis Project
	EIA: Energy Information Administration
	NEI: National Emissions Inventory
	EPA: US Environmental Protection Agency
	TATP: terrestrial Air temperature and Precipitation

Table 4: Results of Correlation Between Variables

	eee	eei	tax	teat	tebt	ipi	GDP-engi	Clean-engi	pgdp
eee	1.0000								
eei	0.5384	1.0000							
tax	0.5628	0.1244	1.0000						
teat	0.7041	0.6430	0.3625	1.0000					
tebt	0.0654	0.0741	0.0501	0.1123	1.0000				
ipi	-0.0061	0.0459	-0.0257	0.0248	0.3729	1.0000			
GDP-engi	0.0469	0.0322	-0.0425	0.0695	-0.1497	0.0316	1.0000		
Clean-engi	-0.0199	-0.0506	0.0714	0.0682	0.0366	-0.1350	-0.0151	1.0000	
pgdp	0.0611	-0.0127	0.3302	0.0110	-0.0133	0.0530	-0.0594	-0.2019	1.0000

source: Author's calculation

Table 5: The average of emission embodied in export and import and carbon tax for 2000-2014

Country	code	Avrg. EEE	Avrg. EEI	Avrg. TAX
Australia	aus	4.333866	2.448189	9.82439
Austria	aut	3.171913	1.109448	9.199505
Belgium	bel	3.631563	1.501685	9.109751
Bulgaria	bgr	1.317903	2.251595	6.863468
Brazil	bra	4.731835	0.903168	9.569214
Canada	can	4.743591	3.001675	9.628018
Switzerland	che	4.364398	4.953213	9.017783
China,P.R.: Mainland	chn	5.873417	1.531579	10.32668
Cyprus	cyp	0.606097	-0.75896	6.339469
Czech Republic	cze	2.692827	1.304548	8.190242
Germany	deu	5.595327	2.628419	11.13234
Denmark	dnk	3.211063	0.43395	9.418893
Spain	esp	4.711672	1.470882	9.988519
Estonia	est	1.040388	2.26524	5.873929
Finland	fin	3.06763	3.045086	8.738397
France	fra	5.349833	2.057578	10.8147
United Kingdom	gbr	5.368024	2.009524	10.96391
Greece	grc	3.181789	3.753736	8.59021
Croatia	hrV	1.698927	2.365659	6.962812
Hungary	hun	2.399131	0.576774	8.005486
Indonesia	idn	3.732976	2.364338	6.390595
India	ind	4.687603	3.394323	9.509916
Ireland	irl	2.943942	0.142313	8.460281
Italy	ita	5.161562	1.680016	10.92206
Japan	jpn	6.135709	1.373636	11.27824
Korea	kor	4.484638	0.324206	10.0608
Lithuania	ltu	1.503241	2.421093	6.386073
Luxembourg	lux	1.743505	1.376073	6.961306
Latvia	lva	0.658696	0.718963	6.261467
Mexico	mex	4.539455	0.997424	4.646045
Malta	mlt	1.200473	2.096202	5.392225
Netherlands	nld	4.127854	1.385222	10.10231
Norway	nor	3.219618	1.238473	9.05885
Poland	poL	3.649839	3.708499	8.948978
Portugal	prt	2.944225	0.527356	8.533854
Romania	rou	2.360318	0.061377	7.724597
Russian Federation	rus	4.210487	2.28709	3.627748
Slovak Republic	svk	1.835597	0.610219	7.139791
Slovenia	svn	1.32824	0.486974	7.183337
Sweden	swe	3.624851	2.13252	9.271265
Turkey	tur	3.896694	2.103904	9.793953
Tanzania	twn	3.664168	2.378884	6.161212
United States	usa	7.213445	5.111513	11.5707