Decomposing patterns of emission intensity in the EU and China: how much does trade matter?

1 Introduction

The Kyoto protocol sets binding targets on international emission reductions. In order to meet a targeted 8% reduction in CO_2 emissions by 2012, European countries adopted, as of 2005, a pricing scheme for their emissions, in order to curtail demand for emission-intensive goods. The Kyoto protocol was the only binding emissions-reduction target in place during the time period covered in our analysis (2005 to 2009); the EU's 20-20-20 targets were subsequently enacted in 2009. The EU emissions trading system (ETS) is a key tool through which Europe is trying to cut industrial greenhouse gas emissions. According to the European Commission: *"by putting a price on carbon and thereby giving a financial value to each tonne of emissions saved, the EU ETS has placed climate change on the agenda of company boards and their financial departments across Europe. A sufficiently high carbon price also promotes investment in clean, low-carbon technologies".* [1] The pricing scheme works as a cap on the total amount of emissions that can be produced, which is imposed on a group of "installations". Within the cap companies are allocated or can buy allowances to produce CO_2 emissions. In 2005 a number of free allowances were allocated. Companies can buy or sell allowances as required through the ETS; the market for emission allowances determines the price of allowances. The sectors of the economy whose factories and installations are not regulated under ETS are bearing the costs of emission prices only indirectly: a change in the ETS allowance price will affect the costs in those sectors whose installations are under emissions regulation and thus the price of their goods, which can be used as intermediate inputs by other sectors of the economy. Identifying the patterns of sectoral emissions of EU countries is therefore a useful way to investigate whether ETS regulation has been effective in controlling emissions. As the Kyoto target assigns responsibility for emissions based on the production and not the consumption of goods, we also investigate the role of the trade between China and Europe in driving emissions.

Our analysis is based on a number of different methods of investigating emissions from production. The first one adopts an accounting perspective and uses macro-indicators of both sectoral emissions and sectoral production. This method allows us to identify the most emission-intensive sectors in European countries and the relative contribution of these sectors to each country's GDP. The second method is based on an input-output methodology, in which we use an input-output price analysis to simulate the effect of a change in the ETS price from €4 to €10/tonne CO_2 in both 2005 and 2009 in order to determine which sectors and which countries are impacted most by this measure.[2]

There is a vast literature on embodied emissions. However, to our knowledge, the literature does not

[1] http://ec.europa.eu/clima/policies/ets/index_en.htm

[2] All values in the World Input-Output Database are specified in US$ and thus the simulated ETS prices are converted into dollar values before conducting the price analysis. Details of the CO_2 scenarios chosen are provided in Section 3.

contain a single complete analysis of sectoral emissions for all EU countries in recent years. By examining emission patterns for all countries in the EU and across 35 production sectors, our study makes an important contribution to the literature on the role played by trade in emission patterns. Our analysis provides new information which could be useful in the process of defining new emission targets.

The input-output model was originally proposed by Leontief (1936); other notable examples of its use include Sraffa (1960), Pasinetti (1973), and Pasinetti (1988) amongst others. Subsequently, Leontief (1970) extended this method to the analysis of greenhouse gas emissions; it has since been used by, for example, Treloar (1997) , Ferng (2003), Mongelli et al. (2006), Liang et al. (2007), Butnar and Llop (2007) and Llop and Tol (2013).

Of particular relevance to our paper are the work of Sánchez-Chliz and Duarte (2004) and Machado et al. (2001) who emphasize the role of trade in explaining the emission patterns of Spain and Brazil in 1995. Both papers highlight the role of trade as a source of emissions; in Spain the importing of goods that are used as intermediate inputs in construction and transport counts for 36% of the total emissions share. Emissions follow the opposite direction in Brazil, which exports emission-intensive goods that count for 14% of emissions. More recently Carvalho et al. (2013) analyse CO_2 emissions and trade between the Minas Gerais state of Brazil and some of its larger trading partners (namely the EU, US, China and Argentina), and conclude that these trading partners are net importers of embodied CO_2 emissions produced by Minas Gerais.

Finally, Tarancón et al. (2010) apply an input-output price analysis to investigate the influence of the manufacturing sector on electricity demand in Europe. We follow this approach to determine which countries and sectors will be most affected by a change in the price of emissions.

Our results show that the sectors and countries considered in our analysis are characterized by different patterns of emission intensity. In particular, sectors under ETS regulation in Central and Eastern EU countries are the most emission-intensive sectors in both of the years analysed. Therefore, a rise in the ETS price will strongly affect these sectors as their levels of emissions are the highest in Europe. At the same time, we find that Central/Eastern EU countries have seen the largest reduction in emission-intensity from 2005 to 2009. Our results also show that the reduction in the emission intensity of production in Central/Eastern European countries was associated with a decrease in the economic importance of the emission-intensive sectors. Thus it is possible to hypothesize that part of the emission-intensive production has been shifted from these countries to other non-European countries where no price is placed upon emissions, i.e., that carbon leakage [3] may be occurring.

[3]Carbon leakage is defined by the IEA as "the increase in emissions outside a region as a direct result of the policy to cap emission in this region", IEA (2008)

To analyse the hypothesis that the reduction of emission intensity in Europe is as a result of emissions being displaced rather than a genuine reduction in the quantity of carbon embodied in goods, we investigate whether the quantity of inputs used in the production process that are imported from China has increased, using multi-regional input-output tables. Other studies, such as Shimoda et al. (2008), find that increases in emissions in China are being partially driven by consumption in other countries. Furthermore, research by Lin and Sun (2010) has found that emissions from production in China are greater than its consumption-based emissions which, the authors state, highlights that carbon leakage is occurring from other countries, and indicates that the current framework for addressing climate change is inadequate. Our results also show a significant increase in the level of imported embodied emissions from China into the EU between 2005 and 2009, but we do not find that this pattern is particular to sectors regulated under ETS.

The rest of the paper is organised as follows. Section 2 describes the database used in the analysis. Section 3 presents the two methods used to decompose sectoral emissions. Section 4 presents the results of the input-output price analysis. Section 5 presents an analysis of trade in intermediate goods from China to the EU. At the end of the paper we provide some concluding remarks.

2 Data description

The emissions data and the input-output tables used in our analysis are from the World Input-Output Database (WIOD: www.wiod.org). This database contains input-output tables and environmental accounts (which includes CO_2 emissions) for 27 EU countries and 13 other major countries in the world between 1995 and 2009. The input-output tables and the emissions data are presented at a 35-sector level of aggregation. While data are available for all years up until 2009, we have chosen to focus on 2005 and 2009 in our analysis so that we could compare patterns of emissions and economic activity before and after the EU ETS was implemented. Focusing on 2005 and on 2009 provides a snapshot of the patterns of emissions and production just before the ETS was implemented, and for the most recent year available in the data. Our analysis focuses on the 27 countries of the EU and on China, and we consider the emissions of CO_2 only. There are a number of data caveats in the WIOD, for example, CO_2 emissions for certain countries are reported as zero in some sectors where it is unlikely that no CO_2 was emitted (e.g., in certain transport sectors in Malta). Details of the methodologies and data sources used to construct the economic tables and the environmental accounts can be found in Genty and Neuwahl (2012) and Timmer (2012); in particular further data caveats are discussed by Timmer (2012). Table 1 shows the sectors that are, on average, in the highest decile of the distribution of emission intensity in the EU, as a whole, in 2005 and 2009 respectively. The pattern of relative emission intensity is reasonably stable between the two years considered.

2005	2009
Other Air Transport	Chemicals and Chemical Products
Chemicals and Chemical Products	Coke, Refined Petroleum and Nuclear Fuel
Coke, Refined Petroleum and Nuclear Fuel	Basic Metals and Fabricated Metal
Other Inland Transport	Other Air Transport
Basic Metals and Fabricated Metal	Other Non-Metallic Minerals
Other Non-Metallic Minerals	Other Inland Transport
Electricity, Gas and Water Supply	Electricity, Gas and Water Supply

Table 1: Emission intensity, highest decile of the distribution, 2005 & 2009

All values in the WIOD input-output tables are given in nominal US $ terms, however we conduct our analysis based on values expressed in real 2005 $ values. In order to deflate the 2009 I-O tables to 2005 values we use the following deflators: for EU countries we use the producer prices deflator [4] for the manufacturing sectors, the harmonised index of consumer prices for the services sectors, and the agricultural output price index for the agricultural sector, all of which are available from Eurostat. To deflate the Chinese input-output tables we use value added deflators for the manufacturing, services and agricultural sectors, available from the World Bank.

3 Methodology

Our analysis can be divided into three parts: first we use statistical indicators to quantify the economic importance of the emission-intensive sectors. Second, we use the Leontief matrix derived from the input-output tables to assess the impact of a change in the emissions price on the different sectors of each of the 27 EU countries. Finally, we use inter-regional input-output tables and environmental accounts to quantify the embodied emissions of Chinese intermediate goods exported to Europe, and we examine how these embodied emissions have changed from 2005 to 2009.

3.1 Statistical indicators

We follow Mendiluce et al. (2010) and Alcántara and Duarte (2004) to calculate the energy intensity of the economy. We distinguish between the 35 sectors of the economy ($s = 1, .., 35$) and the 27 EU countries

[4] Producer price deflators are missing for Portugal in all years, and thus we deflate the Portuguese I-O tables using the producer price deflator for Spain. Similarly data are missing for Slovakia in some years, and for these years we use the deflator for the Czech Republic.

($i = 1, .., 27$). The energy intensity indicator is described by the following Equation:

$$\frac{E_i}{Y_i} = \sum_{s=1}^{N} \frac{E_{s,i}}{Y_{s,i}} \frac{Y_{s,i}}{Y_i} \tag{1}$$

The left term in Equation 1 is the emission intensity in country i, calculated as the ratio between the emissions of country i (E_i) and its GDP (Y_i). The first term on the right side of Equation 1 is the sectoral emission intensity. The ratio ($\frac{E_{s,i}}{Y_{s,i}}$) shows the emissions in the s sector of country i divided by sectoral GDP, and the term $\frac{Y_{s,i}}{Y_i}$ measures how much sector s contributes to country i's GDP. Thus the indicator allows emission intensity to be decomposed into sectoral emission intensity and output intensity. N is the number of sectors, equal to 35.

3.2 Input Output price analysis

The main assumption behind the input-output model is that, for each year, each industry consumes the output of other industries in a fixed ratio, in order to produce its output. We follow the price model outlined in Tarancón et al. (2010). The basic equation that describes the linear relationships between the sectors of each country is:

$$x = Ax + y \tag{2}$$

Where x is the total output required, y is the final demand/consumption and A is the matrix of technological coefficients (a_{ij}), that represent the input required by another sector to produce a unit of monetary output. Thus, Ax is the n-vector of intermediate demand, and

$$a_{ij} = \frac{x_{ij}}{x_i} \tag{3}$$

Solving for x leads to:

$$x = (I - A)^{-1} y \tag{4}$$

Where I is the identity matrix and $(I - A)^{-1}$ is the Leontief inverse matrix. The environmental extension of the basic IO model described by Equation 4 can be obtained by multiplying the Leontief matrix by the environmental matrix E, which contains the emission coefficients, i.e., CO_2 emitted by each sector to produce one unit of output. [5]

$$M = E(I - A)^{-1} y \tag{5}$$

[5]The environmental matrix has been widely used in literature. See, among others Treloar (1997), Lenzen (1998),Machado et al. (2001), Ferng (2003), Alcántara and Duarte (2004), Sánchez-Chliz and Duarte (2004), Mongelli et al. (2006), Liang et al. (2007) and Butnar and Llop (2007)

In which M gives the total (direct and indirect) CO_2 emissions of each sector.

Following Tarancón et al. (2010), the input-output model allows us to simulate the effects of a change in the ETS price on the productive sectors. We identify the changes in the cost of different sectors as a result of the changes in the value of the energy inputs. Specifically, we investigate the effects of a rise in the ETS allowance price. One of the problems with the EU's ETS since its inception has been the consistently low price of carbon due to a surplus of ETS permits [6]. Such low prices are not sufficient to deter the emission of CO_2 or to encourage investment in low-carbon technologies. The causes and consequences of the low carbon prices have been discussed in, for example, Betz et al. (2006) and Laing et al. (2013). Recently the European Commission has been considering how to reduce the surplus of ETS permits; amongst options being considered are the "back-loading" of permits, i.e. postponing the auction of permits until 2019/2020. Point Carbon (Carbon Market Trader Team (2012)) have considered the options for increasing the price of permits, and estimated the resulting permit prices that would come from various EU policies. Under the "political inaction" scenario the price of carbon is €4/tonne CO_2 in 2013 (the first year of their projections). On the other hand, when they consider a scenario which involves the back-loading of 900 million allowances and the cancelation of 900 million more, they project a carbon price in 2013 of €10/tonne CO_2. Through an input-output price model we simulate the impact of such an increase in carbon prices (from €4 to €10/tonne CO_2 [7]). We simulate the same increase in the price of ETS permits in 2005 and 2009 as doing so provides a useful way of looking at the underlying interdependencies of the European production system, and their changes over time. Focusing on 2005 and 2009 provides a snapshot of the situation in the year when the ETS was launched - 2005, and for the most recent year in the WIOD data - 2009.

Under the ETS certain factories/installations are regulated. The input-output table does not provide information at this level of detail, so we make the simplifying assumption that the following sectors are regulated:

[6] The price of ETS permits reached a record high of approximately €30/tonne in early 2006, but plummeted to almost €0 per tonne in 2007 (Siikamki et al., 2012)

[7] As all values in the WIOD are expressed in dollar terms, we convert these prices to real 2005 dollar values before running the price model.

Mining and Quarrying
Pulp, Paper, Printing and Publishing
Coke, Refined Petroleum and Nuclear Fuel
Chemicals and Chemical Products
Non-Metallic Minerals
Basic Metals and Fabricated Metal
Electricity, Gas and Water Supply

Table 2: Sectors regulated under ETS

We assume that all the other sectors pay a carbon tax equal to \$1/tonne CO_2 that is kept constant over time in order to disentangle the effects of the change in the ETS price only. Changing the allowance price will have a direct effect on the sectors regulated under the ETS, and an indirect effect on the prices of the sectors not directly regulated by the ETS. This indirect effect can be interpreted as an indicator of the pressure that the cost functions of different sectors bear as a result of the increase in the prices of the emissions, and thus of the energy inputs, given the chain of the productive relationships captured by the input-output system. The value of the output of sector s in country i will be equal to the value of the intermediate consumption and the value of the primary inputs (such as wages, taxes and energy). This relation can be expressed as:

$$x^q_{s,i} p_{x_{s,i}} = a_{1s,i} x^q_{s,i} p_{x_{1i}} + a_{2s,i} x^q_{s,i} p_{x_{2i}} + ... + a_{ns,i} x^q_{s,i} p_{x_{ni}} + z^q_{s,i} p_{z_{s,i}} \tag{6}$$

where z is the vector of the primary inputs, p refers to the prices and q refers to physical units. Dividing the previous equation by the physical output leads to:

$$p_{x_{s,i}} = a_{1s,i} p_{x_{1i}} + a_{2s,i} p_{x_{2,i}} + ... + a_{ns,i} p_{x_{ni}} + \delta_{s,i} p_{z_{s,i}} \tag{7}$$

in which $\delta_{s,i}$ is the ratio between the primary input of the sector s in country i and its output, and $p_{x_{s,i}}$ is the price of the goods produced by sector s in country i. Initially, all these prices will be assumed equal to 1. Prices of goods and services produced by sector s of each country can be related to the changes in the prices of primary inputs. In particular, in this paper we assume that the only change in the primary input prices will be the change in the emission price, which affects the cost of energy. We can calculate the variation of the final prices after the change in the ETS price with the following:

$$p_{x_{s,i}} = \sum_{q=1}^{n} l_{qs,i} \delta_{s,i} q \tag{8}$$

where $l_{qs,i}$ is the element of column s of the Leontief matrix of country i. The emission intensity of each sector will determine the impact of the variation of the ETS price on that sector's price; moreover, through the relations described by the input-output tables, the change of the price of the sector s will generate variations in the price of other goods. Emission-intensive sectors or sectors that use emission-intensive goods as intermediate inputs will experience greater increases in their final costs relative to the low-emission sectors, or sectors that do not use emission-intensive intermediates.

4 Results

4.1 Emission intensity

The emission-intensity indicator described by Equation 1 may be used to compare the sectoral emissions of each country. Our analysis shows that the ratio of sectoral emissions to total GDP experienced a stronger contraction in the Central/Eastern European countries than in the other regions between 2005 and 2009, as shown in Table 3.

	2005	2009	Avg. annual % change
Great Britain	0.112	0.120	1.76
Ireland	0.079	0.059	**-7.12**
Germany	0.137	0.115	**-4.41**
France	0.076	0.058	**-6.37**
Sweden	0.073	0.069	**-1.12**
Austria	0.100	0.072	**-7.83**
Belgium	0.128	0.102	**-5.38**
Finland	0.146	0.125	**-3.81**
Luxembourg	0.038	0.024	**-10.89**
Netherlands	0.140	0.117	**-4.48**
Denmark	0.171	0.156	**-2.22**
Spain	0.131	0.062	**-17.00**
Italy	0.112	0.089	**-5.68**
Cyprus	0.255	0.200	**-5.89**
Greece	0.252	0.216	**-3.76**
Malta	0.201	0.167	**-4.44**
Portugal	0.180	0.130	**-7.69**
Estonia	0.503	0.463	**-2.05**
Slovakia	0.348	0.175	**-15.88**
Slovenia	0.183	0.151	**-4.65**
Poland	0.471	0.354	**-6.94**
Romania	0.490	0.319	**-10.18**
Bulgaria	0.786	0.503	**-10.57**
Czech Rep	0.341	0.222	**-10.19**
Hungary	0.204	0.194	**-1.31**
Latvia	0.221	0.194	**-3.22**
Lithuania	0.280	0.221	**-5.76**

Table 3: Total emission intensity, 2005 & 2009

For Europe as a whole, the production of emission-intensive goods contracted from 2005 to 2009. Table 3 shows that the highest contraction of emission intensity generally happened in the Central/Eastern EU countries, with the exception of Spain where the contraction in emission intensity was particularly large at 17%. For the countries in Central and Eastern Europe, many of them joined the EU in May 2004. It is possible that the part of the decline of emission intensity shown in Table 3 above was a result of an improvement in the technologies used by industries after accession to the EU. It is likely that this effect would not have yet been visible in 2005, but would have been by 2009 [8]

4.2 Sectoral analysis and ETS impact

The results of our analysis on emissions intensity highlights the importance of the introduction of ETS in 2005, as it might have changed the performance of the ETS sectors (shown in Table 2) with respect to the other sectors of the economy [9]. In order to see whether sectors under emission-price regulation perform differently vis-à-vis other sectors, we separate the ETS from the non-ETS sectors. Table 4 allows us to compare the variation in the sectoral emissions between the regulated and non-regulated sectors (i.e., ETS and non ETS) in 2005 and 2009.

[8] We are grateful to an anonymous referee for bringing this possible explanation to our attention.

[9] In this section of the paper we focus on the ratio between sectoral emissions and sectoral GDP as this gives a measure of the impact of the ETS pricing on sectoral emissions, and is useful to show the patterns in different EU countries. As an increase in the ETS price will also affect the final prices of the various sectors, through direct and indirect channels, we present a detailed analysis of the effects of a variation in the ETS price on the economies of EU countries in Section 4.3

	Change in sectoral emission intensity			Change in output intensity		
	ETS	*Non-ETS*	*Difference*	*ETS*	*Non-ETS*	*Difference*
Great Britain	3.69	5.18	1.48	-4.47	0.57	5.04
Ireland	-10.72	-6.58	4.14	5.01	-1.12	**-6.13**
Germany	-6.34	-3.35	2.99	-0.43	0.07	0.50
France	-8.78	-1.43	7.35	0.64	-0.09	**-0.73**
Sweden	-0.49	3.98	4.48	-2.34	0.40	2.74
Austria	-6.95	-5.14	1.81	1.74	-0.33	**-2.07**
Belgium	-7.00	4.65	11.64	-2.10	0.45	2.55
Finland	-6.16	-2.32	3.84	-1.81	0.37	2.18
Luxembourg	-4.69	-12.10	**-7.40**	-7.67	0.54	8.21
Netherlands	-7.49	3.95	11.44	-1.39	0.28	1.67
Denmark	-2.40	-0.12	2.28	-4.33	0.54	4.87
Spain	-16.00	-6.98	9.02	-1.01	0.17	1.18
Italy	-5.82	-1.36	4.47	-1.92	0.33	2.24
Cyprus	-4.85	-10.57	**-5.72**	-1.23	0.11	1.35
Greece	-3.23	5.84	9.07	-2.26	0.29	2.55
Malta	15.98	-2.59	**-18.57**	4.44	-0.53	**-4.97**
Portugal	-8.49	-5.04	3.46	0.85	-0.13	**-0.98**
Estonia	-2.74	6.22	8.96	2.54	-0.33	**-2.87**
Slovakia	-11.82	-13.73	**-1.90**	-1.24	0.33	1.57
Slovenia	-8.62	-0.53	8.09	-1.80	0.35	2.15
Poland	-7.31	0.79	8.10	-0.35	0.07	0.42
Romania	-10.80	-10.48	0.32	-2.16	0.48	2.64
Bulgaria	-10.57	-8.92	1.65	1.56	-0.46	**-2.02**
Czech Rep	-10.69	-4.84	5.86	-2.70	0.58	3.27
Hungary	-2.74	3.22	5.96	0.55	-0.10	**-0.65**
Latvia	-7.26	0.80	8.06	2.83	-0.29	**-3.12**
Lithuania	-7.02	-0.64	6.39	-1.57	0.37	1.94

Table 4: Change in emission intensity and output intensity from 2005 to 2009 - ETS vs non-ETS sectors

As Table 4 shows, all EU countries have experienced a strong reduction in emission intensity in the ETS sectors, with the exceptions of Malta, Cyprus and Luxemburg. Moreover, the decline in the emission-intensity of the ETS sectors generally happened concurrently with a reduction in output intensity of these sectors. The particularly large contraction of emission intensity in the ETS-regulated sectors suggests this reduction can be partially attributed to the ETS, adopted in 2005. However, the change in output intensity highlights that the production intensity of the more polluting sectors has decreased between 2005 and 2009.

It is worth noting that countries in Central/Eastern Europe show a slightly higher overall change in the patterns of emission-intensity relative to the other groups of countries. There are two factors that explain the reduction in emission intensity in Central/Eastern EU states. On one hand the GDP of countries in Central/Eastern Europe has grown quite rapidly from 2005 and 2009; thus the denominator of the emission-intensity indicator has increased. On the other hand, the emissions, in absolute terms, have decreased for all the EU countries, including the Central/Eastern countries. This second effect may be influenced by the adoption of the emissions-pricing scheme, and by the relocation of the production of highly emission-intensive goods to other countries (such as China). However, the data used in this analysis do not allow us to fully identify these two effects. Thus, in order to give a partial explanation of the latter effect, in Section 5 we analyse the imports of goods (and thus, embodied emissions) from China.

4.3 Effects of ETS price variation

Our previous results suggest that the introduction of ETS prices may have affected emission intensity across the EU. We use Equation 8 to determine the impact of a change in the emission price on different countries and different sectors, and look at how a simulated change in the ETS price affects the price of final output in 2005 and 2009. Table 5 shows the results for all the sectors - as anticipated, the simulated price increase has a weaker effect in 2009, relative to 2005, due to reduction in the emission-intensity of production. Furthermore, as expected, ETS-regulated sectors are much more strongly affected by the price variations than the non-ETS sectors (that bear the cost of the ETS price increase only indirectly). Given the higher levels of CO_2 emitted in their production process, the Central/Eastern European countries are affected more by the ETS price change than the other European countries, both in 2005 and in 2009.

Note that we are simulating an identical price increase in the ETS-regulated sectors in both years. Therefore, what the following tables are showing is that the effect of an increase in the price of allowances is less strong in 2009, compared to 2005 (as shown in the "Difference" column), reflecting the general decarbonisation of the European production sector over this period.

	Northern			Mediterranean			Central/Eastern		
	2005	2009	Difference	2005	2009	Difference	2005	2009	Difference
ETS sectors:									
Mining and Quarying	0.25%	0.25%	0.00%	0.95%	1.02%	0.08%	0.60%	0.46%	-0.14%
Pulp, Paper, Printing and Publishing	0.11%	0.11%	0.00%	0.21%	0.18%	-0.02%	0.37%	0.25%	-0.12%
Coke, Refined Petroleum and Nuclear Fuel	0.31%	0.33%	0.02%	0.23%	0.40%	0.17%	1.12%	1.50%	0.37%
Chemicals and Chemical Products	0.16%	0.14%	-0.02%	0.27%	0.21%	-0.06%	1.11%	0.75%	-0.36%
Other Non-Metallic Minerals	0.73%	0.70%	-0.03%	1.17%	1.04%	-0.13%	1.59%	1.33%	-0.26%
Basic Metals and Fabricated Metal	0.27%	0.25%	-0.02%	0.40%	0.77%	0.37%	0.78%	0.51%	-0.27%
Electricity, Gas and Water Supply	1.43%	1.26%	-0.17%	2.84%	2.26%	-0.58%	4.30%	3.27%	-1.03%
Average ETS sectors	*0.47%*	*0.43%*	*-0.03%*	*0.86%*	*0.84%*	*-0.02%*	*1.41%*	*1.15%*	*-0.26%*
Non-ETS sectors:									
Agriculture	0.04%	0.04%	0.00%	0.11%	0.11%	-0.01%	0.17%	0.14%	-0.03%
Non-ETS Manufacturing	0.04%	0.04%	0.00%	0.12%	0.11%	-0.01%	0.18%	0.14%	-0.04%
Transport	0.03%	0.02%	0.00%	0.07%	0.06%	-0.02%	0.13%	0.12%	-0.01%
Services	0.02%	0.02%	0.00%	0.07%	0.06%	-0.01%	0.14%	0.12%	-0.02%
Average non-ETS sectors	*0.03%*	*0.03%*	*0.00%*	*0.10%*	*0.08%*	*-0.01%*	*0.15%*	*0.13%*	*-0.03%*

Non-ETS manufacturing sectors are: Food, Beverages and Tobacco; Textiles and Textile Products; Leather and Footware Wood and Products of Wood and Cork; Rubber and Plastics; Machinery, Electrical and Optical Equipment; Transport Equipment Manufacturing, Recycling. Services sectors are: Construction; Sale, Maintenance and Repair of Motor Vehicles and Motorcycles; Retail sale of fuel; Wholesale Trade and Commission Trade, Except Motor Vehicle and Motorcycles; Retail Trade; Repair of Household goods Hotels and Restaurants; Other Supporting and Auxiliary Transporting Activities; Activities of Travel Agencies; Post and Telecommunications; Financial Intermediation; Real Estate Activities; Renting of Machinery and Equipment and Other Business Activities; Public Admin and Defence; Compulsory Social Security Education; Health and Social Work and Personal Services

Table 5: Final price change after the variation of ETS price (2005 & 2009)

5 Exports from China and embodied CO_2 emissions

The analysis to this point suggests that in general all regions in Europe are reducing the emission intensity of their production processes; and that this is particularly true for those sectors regulated under the EU-ETS. This is an important and positive finding if industries within the region are embracing more environmentally-friendly production processes, however it is also possible that we are seeing a reduction in the emission-intensity of production due to carbon leakage. Helm et al. (2007), looking at this issue for the UK, have stressed that a country could produce low-carbon-intensity goods but import and consume goods that are highly carbon-intensive. According to the current UNFCCC methodology such a country would have low carbon intensity. Helm estimates that, in the UK, consumption-based emissions have risen by 19% from 1990-2003; this is in stark contrast to the *reduction* in emissions it has achieved according to the UNFCCC methodology, which accounts only for emissions from production. A large part of the fall in productive emissions experienced by the UK has been as a result of the changing structure of production away from energy- and emission-intensive goods, many of which are now imported from China, India and other developing countries. In this part of our analysis we wish to examine whether the same pattern holds for production at a European level, with a focus on imported intermediate goods, i.e. goods that are used as inputs in the production process. It is possible that the reduction which we have seen in emission intensity across Europe has been a result of firms choosing to import carbon-intensive intermediate goods (as well as carbon-intensive finished products) from China rather than producing them domestically.

Of course the EU has many trading partners besides China but our decision to focus on intermediate goods from China was motivated by the fact that over the period of our analysis there has been a notable increase in the amount of intermediate goods used in the European production process that come from China. According to the WIOD, from 2005 to 2009 the value of Chinese intermediates used in the EU production process has increased by 158%, in nominal terms; this is in contrast to a nominal increase of 16% and 10% in the value of intermediates imported from the NAFTA [10] and BRIIAT [11] regions respectively, and a reduction of 8% in the nominal value of intermediates imported from East Asia.

5.1 Patterns of emission intensity: Europe and China

The graph below illustrates the relative emissions intensity (defined as emissions divided by output in real 2005 $ terms) in Europe and China for the ten most polluting sectors in China, in 2005 and 2009; it shows that the Chinese economy is significantly more emission intensive than that of Europe, but that both regions have achieved reductions in emission intensity in recent years. However, over this period there has been an

[10] North American Free Trade Agreement

[11] Brazil, Russia, India, Indonesia, Australia and Turkey

increase in the real emission intensity in some sectors in China; Figure 1 shows that the emission intensities of the air and water transport sectors in China have increased from 2005 to 2009.[12] Emission intensity is calculated as sectoral CO_2 emissions divided by sectoral output (in real 2005 $ values).

Figure 1: Emission intensity of output 2005 and 2009: EU and China

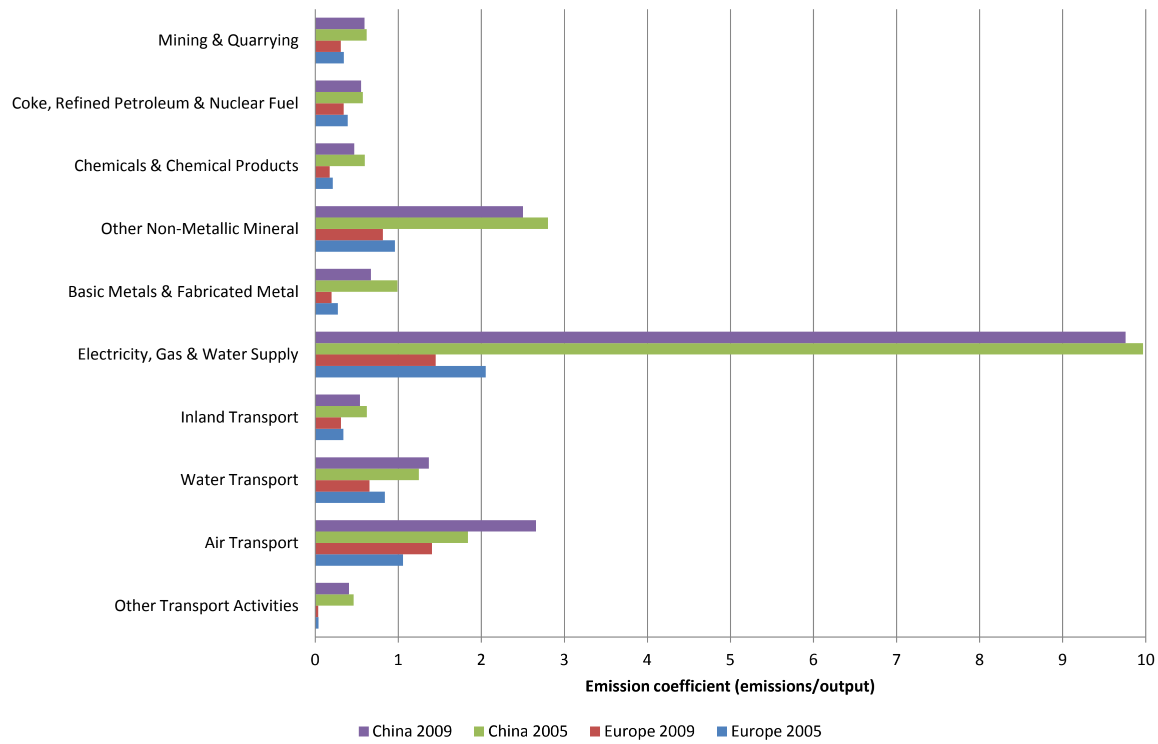

Figure 1 shows that while both regions are reducing the carbon intensity of production, the level of carbon intensity in China remains far above that of Europe; this implies that if intermediate goods, previously produced in Europe, are now being produced in China, global CO_2 emissions driven by the European production process will have risen in a way that is not captured by the producer-pays definition of environmental responsibility. The producer-pays principle would attribute these emissions to China, whereas a consumer-pays definition of environmental responsibility would attribute responsibility for these emissions to European consumers, if the finished goods are ultimately consumed in Europe. As explained by Helm et al. (2007), the calculation of emissions on a consumption-basis would include all greenhouse gases embodied in a country's consumption and, therefore, trade should be accounted for such that the GHGs embodied in imported goods are added, and those embodied in exported goods are subtracted in the calculation.

Figure 1 also illustrates that using a single region input-output analysis to approximate the embodied

[12] An anonymous referee highlighted the fact that some of the changes in sectoral emission intensity in China, shown in the data, may be partially attributable to improved data at lower levels of aggregation. While we acknowledge that this may be the case, we have no way of verifying this and, as such, we take the data at face value.

emissions imported into Europe from China would lead to a significant under-counting of embodied emissions, as the Chinese production process is much more emission-intensive than that of the EU.

5.2 Embodied emissions

To examine the quantity of intermediate goods that are used in the European production process but produced in China we make use of the Interregional Input-Output tables, available via the World Input-Output Database. We combined data from the Eurozone and "Other EU" countries to look at the quantity of Chinese inputs used in the total EU production process. This allows us to look at the proportion of inputs used in each sector that come from China, and thus quantify the embodied emissions imported into the European production process.

Figure 2: The ratio of Chinese to European intermediate inputs used in the EU, 2005 and 2009

ETS sectors	**2005**	**2009**
Mining and Quarrying	0.53%	0.93%
Pulp, Paper, Paper , Printing and Publishing	0.41%	0.74%
Coke, Refined Petroleum and Nuclear Fuel	0.41%	0.61%
Chemicals and Chemical Products	0.73%	1.24%
Other Non-Metallic Mineral	0.50%	0.85%
Basic Metals and Fabricated Metal	0.79%	1.09%
Electricity, Gas and Water Supply	0.44%	0.68%
Non-ETS sectors		
Agriculture, Hunting, Forestry and Fishing	0.34%	0.56%
Manufacturing	1.25%	1.96%
Transport	0.62%	1.13%
Services	0.53%	0.98%

The majority of intermediate inputs used within the European production process come from within the EU, however the ratio of inputs sourced from China to inputs sourced from within the EU increased from 2005 to 2009, as illustrated by Figure 2. Indeed while the overall proportion of inputs sourced from China is low, in the majority of sectors analysed it has increased significantly from 2005 to 2009. This is true for both "clean" industries, such as much of the services sector, and for "dirty" industries such mining and quarrying, and the production of chemical products. Overall this has led to an increase in the proportion of "embodied" emissions entering the EU production process from China, despite the declining emission intensity of the Chinese economy.

For some sectors the increase is in embodied emissions in absolute terms is particularly large. Looking at the sector producing "other non-metallic mineral products", the ratio of Chinese to European inputs increased by 71% from 2005 to 2009. This has resulted in an increase in the absolute quantity of embodied CO_2 imported from this sector of over 1,000 ktCO_2. The sector where the increase in embodied emissions was largest is electricity, gas and water supply. The ratio of Chinese to European intermediates increased by 53% from 2005 to 2009. This translates to an additional 12,700 ktCO_2 embodied in the intermediate goods imported from China and used by this sector.

While Figure 2 shows that there has been a rise in the imported Chinese intermediates in all sectors from 2005 to 2009, it also shows that this pattern is not particularly notable in the sectors covered by the ETS. This could be indicative of the low price of ETS allowances since they have been introduced, which has been partially driven by an excess supply of ETS allowances (see Granados and Carpintero (2013) and Anderson and DiMaria (2011)). The fact that the increase in intermediates imported from China is not higher in the sectors covered by the ETS indicates that for European firms other costs, such as the costs of energy, raw materials and labour, are more important than the costs of pollution when making production decisions. This is unsurprising because, as discussed in Section 3, the price of ETS permits may not have been sufficiently high to alter behaviour of ETS-regulated firms; however, proposals by the EC to increase the price of carbon (via back-loading of permits) may alter this in the future. Table 6 below shows the value of intermediate inputs imported into the EU production process from China in 2005 and 2009 for the ETS sectors, and the average across all other sectors; it also shows the average annual percentage change over the period. All sectors saw an increase over the period. The highest growth was seen in the "Electricity, Gas and Water Supply" sector, which saw the proportion of inputs sources from China grow by, on average, approximately 19% per annum over the period. However, the average annual growth amongst the non-ETS sectors, at 16%, is not significantly below this.

	2005	2009	Average annual % change
Mining and Quarying	292	501	14.47
Pulp, Paper, Paper, Printing and Publishing	1138	1972	14.74
Coke, Refined Petroleum and Nuclear Fuel	624	1153	16.59
Chemicals and Chemical Products	3053	5444	15.55
Other Non-Metallic Minerals	731	1220	13.66
Basic Metals and Fabricated Metal	4174	6133	10.10
Electricity, Gas and Water Supply	1365	2695	18.54
Other sectors (average)	2748	4978	16.01

Table 6: Chinese Intermediate goods used in the EU production process (million $)

6 Conclusions

In this paper we analysed the patterns of CO_2 emissions in Europe through statistical indicators and through an input-output methodology. Our results show that the abatement of CO_2 emissions in all the EU countries is mainly due to the reduction of the emissions in the most emission-intensive sectors, regulated by the ETS. Moreover, the output from the more CO_2-intensive sectors has decreased from 2005 to 2009 more than proportionally relative to the non-ETS sectors. This result suggests that the relocation of the production of these sectors out of Europe may have played an important role in the reduction of the emission-intensity of the European production process. We also found that the pattern of emission intensities varies across EU countries. In particular, emission intensity decreased somewhat more rapidly in Central/Eastern European countries compared to the rest of EU. This is due to GDP growth in these countries, which increased quite rapidly from 2005 to 2009; thus the denominator of the emission-intensity indicator has increased. It could also be a result of improvements in the technologies used in industrial sectors in these countries following their ascension to the EU.

In order to detect the sensitivity of emission intensities to a variation in the ETS price, we follow the methodology used by Tarancón et al. (2010) and employ an input-output price model to simulate the effect that a rise in the price of EU-ETS allowances, from €4 to €10/tonne CO_2, would have on the final price of goods in each EU country and sector in both 2005 and 2009. We find that all countries in the EU reduced the emission-intensity of their production processes over the period, and that the reduction was greatest in those sectors regulated under the ETS. Central/Eastern EU countries are the most strongly affected by the simulated price increase as their emission levels are the highest in Europe.

Furthermore, in order to investigate whether the reduction of European emission and output intensity from 2005 to 2009 was associated with a shift in the production of emission-intensive goods from European to non-European countries we examine how imports of intermediate goods into the EU from China have evolved over the period. Our results show that, while emissions embodied in imported intermediates have increased from 2005 to 2009, this increase is not limited to, nor particularly notable in, the sectors regulated by the ETS.

There are two important policy implications that can be drawn from our analysis, the first relates to border carbon adjustments. Based the significant reductions in the emission-intensity of the more pollutant sectors in the EU, we can conclude that while the price of permits under ETS have been low, the existence of a cap-and-trade system has encouraged reductions in the carbon-intensity of production. However, the fact that this has been accompanied by a decrease in the economic importance of these sectors is indicative that carbon-leakage may be a legitimate concern. This would suggest that the EU should consider the adoption of border carbon adjustments, as discussed by Helm et al. (2012). While the results of our analysis of trade between the EU and China do not indicate a surge in imports into the ETS-regulated sectors, carbon leakage is likely to become more of a concern as the price of ETS permits increase.

The second policy implication relates to the method of allocating responsibility for CO_2 emissions. The current methodology adopted by the UNFCCC allocates responsibility for emissions based on their production. Data from the WIOD show that while some sectors may produce a low level of emissions, they may use highly emission-intensive intermediates in their production processes. Thus while such sectors are not directly emitting, demand for their final produce is driving emissions in other sectors, and countries. This is of particular concern if this demand is driving emissions in regions when the emission of CO_2 is unregulated. Thus we would recommend that policy makers consider a move towards the allocation of emission responsibility on the basis of consumption rather than production, which would allocate the responsibility for greenhouse gases to the consumer of the finished goods, rather than to the producer. Such a calculation should, as noted by Helm et al. (2007), adjust for emissions embedded in imported and exported goods.

References

Alcántara, V. and Duarte, R., 2004. Comparison of energy intensities in European Union countries. Results of a structural decomposition analysis. *Energy Policy*, 32(2), 177 – 189.

Anderson, B. and DiMaria, C., 2011. Abatement and Allocation in the Pilot Phase of the EU ETS. *Environmental & Resource Economics*, 48(1), 83–103.

Betz, R., Rogge, K., and Schleich, J., 2006. EU emissions trading: an early analysis of national allocation plans for 2008–2012. *Climate Policy*, 6(4), 361–394.

Butnar, I. and Llop, M., 2007. Composition of greenhouse gas emissions in Spain: An inputoutput analysis. *Ecological Economics*, 61(2-3), 388 – 395.

Carbon Market Trader Team, P. C., 2012. Make or break for the carbon market: Last chance for short term fix of the EU ETS before new Parliament and Commission in 2014. Technical report, Point Carbon.

Carvalho, T. S., Santiago, F. S., and Perobelli, F. S., 2013. International trade and emissions: The case of the Minas Gerais state 2005. *Energy Economics*, 40, 383 – 395.

Ferng, J.-J., 2003. Allocating the responsibility of CO2 over-emissions from the perspectives of benefit principle and ecological deficit. *Ecological Economics*, 46(1), 121 – 141.

Genty, A. I., A. and Neuwahl, F., 2012. *Final Database of Environmental Satellite Accounts: Technical Report on Their Compilation*. WIOD.

Granados, J. A. T. and Carpintero, O., 2013. *Combating Climate Change: An Agricultural Perspective*, chapter Dynamics and Economic Aspects of Climate Change. CRC Press.

Helm, D., Hepburn, C., and Ruta, G., 2012. Trade, climate change, and the political game theory of border carbon adjustments. *Oxford review of economic policy*, 28(2), 368–394.

Helm, D., Smale, R., and Phillips, J., 2007. Too Good to be True? The UK's Climate Change Record.

IEA, 2008. Climate Policy and Carbon Leakage: Impacts of the European Emissions Trading Scheme on Aluminium. Technical report.

Laing, T., Sato, M., Grubb, M., and Comberti, C., 2013. Assessing the effectiveness of the EU Emissions Trading System. *Grantham Research Institute on Climate Change and the Environment*.

Lenzen, M., 1998. Primary energy and greenhouse gases embodied in Australian final consumption: an input-output analysis. *Energy Policy*, 26(6), 495–506.

Leontief, W., 1936. Quantitative input and output relations in the economic systems of the United States. *The Review of Economics and Statistics*, 18(3), 105–125.

Leontief, W., 1970. Environmental repercussions and the economic structure: an input-output approach. *The Review of Economics and Statistics*, 52(3), 262–271.

Liang, Q.-M., Fan, Y., and Wei, Y.-M., 2007. Multi-regional input-output model for regional energy requirements and CO2 emissions in China. *Energy Policy*, 35(3), 1685 – 1700.

Lin, B. and Sun, C., 2010. Evaluating carbon dioxide emissions in international trade of China. *Energy Policy*, 38(1), 613 – 621.

Llop, M. and Tol, R. S., 2013. Decomposition of sectoral greenhouse gas emissions: a subsystem input-output model for the Republic of Ireland. *Journal of Environmental Planning and Management*, 56(9), 1316–1331.

Machado, G., Schaeffer, R., and Worrell, E., 2001. Energy and carbon embodied in the international trade of Brazil: an input-output approach. *Ecological Economics*, 39(3), 409 – 424.

Mendiluce, M., Perez-Arriaga, I., and Ocana, C., 2010. Comparison of the evolution of energy intensity in Spain and in the EU15. Why is Spain different? *Energy Policy*, 38(1), 639 – 645.

Mongelli, I., Tassielli, G., and Notarnicola, B., 2006. Global warming agreements, international trade and energy/carbon embodiments: an input-output approach to the Italian case. *Energy Policy*, 34(1), 88–100.

Pasinetti, L. L., 1973. The Notion of Vertical Integration in Economic Analysis. *Metroeconomica*, 25(1), 1–29.

Pasinetti, L. L., 1988. Growing Subsystems, Vertically Hyper-integrated Sectors and the Labour Theory of Value. *Cambridge Journal of Economics*, 12(1), 125–34.

Sánchez-Chliz, J. and Duarte, R., 2004. CO2 emissions embodied in international trade: evidence for Spain. *Energy Policy*, 32(18), 1999 – 2005.

Shimoda, M., Watanabe, T., Ye, Z., and Fujikawa, K., 2008. An empirical study on interdependency of environmental load and international IO structure in the Asia-Pacific region.

Siikamki, J., Munnings, C., and Ferris, J., 2012. The European Union Emissions Trading System. *RFF Backgrounder*.

Sraffa, P., 1960. *Production of commodities by means of commodities*. Cambridge University Press.

Tarancón, M. A., del Rao, P., and Albiana, F. C., 2010. Assessing the influence of manufacturing sectors on electricity demand. A cross-country input-output approach. *Energy Policy*, 38(4), 1900 – 1908.

Timmer, M. E., 2012. *The World Input-Output Database (WIOD): Contents, Sources and Methods. April 2012, Version 0.9.*

Treloar, G. J., 1997. Extracting Embodied Energy Paths from Input-Output Tables: Towards an Input-Output-based Hybrid Energy Analysis Method. *Economic Systems Research*, 9(4), 375–391.