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

Valeria Di Cosmo and Marie Hyland *

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Abstract

This paper uses data from the recently available World Input Output Database (WIOD) to examine channels through which CO_2 emissions are embodied within and imported into the European production process. We apply a metric to calculate sectoral emission intensity and thus rank countries and sectors in the EU in terms of their emission intensity, and look at the evolution of patterns of emission intensity in 2005 and in 2009. We use an input-output price model to simulate the effect that a rise in the price of EU-ETS permits, from €17 to €25 /tonne, would have on the final price of goods in each EU country and sector. We find that all countries in the EU are reducing the emission-intensity of their production processes from 2005 to 2009, and we find that the reduction is greatest in those sectors regulated under the ETS. Comparisons of emission intensity between countries show that industries in Central and Eastern Europe are more emission intensive than those of Northern Europe, where industries import emission-intensive goods rather than producing them domestically. Finally we examine the trade in intermediate goods between the EU and China to examine possible increases in carbon leakage from 2005 to 2009. Results show that while emissions embodied in imported intermediate goods have increased from 2005 to 2009, this increase is not limited to, nor particularly notable in, the sectors regulated by the ETS.

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*Economic and Social Research Institute and Trinity College Dublin. e-mail: valeria.dicosmo@esri.ie.

1 Introduction

The Kyoto protocol sets binding targets on international emission reductions. In order to meet the target of an 8% reduction in emissions by 2012, European countries adopted, as of 2005, a pricing scheme for their emissions, in order to curtail demand for emission-intensive goods. As stated on the climate policy web page of 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 emissions imposed on a group of sectors. In 2005 a number of free allowances were allocated through the operators. Above the cap, the emissions are subjected to a pricing rule, called Emission Trading Scheme (ETS), under which the emissions market determines the price of emission permits. The sectors of the economy which are not regulated under ETS are bearing the costs of emission prices only indirectly: a change in the ETS will affect the costs of the sectors under emission regulation and thus the price of their goods, which can be used as intermediate inputs by the other sectors of the economy. Determining 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 in driving emissions across different European countries.

Our analysis is based on two different methods for investigating the 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 a subsystem input-output methodology, which uses linear relationships between the sectors of each country to decompose sectoral emissions in the production system. Finally, we use an input-output price analysis to simulate the effect of a change in the ETS price from €17 to €25 /tonne CO_2 in both 2005 and 2009 in order to determine which sectors and which countries are more likely to be affected by this measure.

There is a vast literature on pollutant emissions. However, to our knowledge, the literature does not 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 subsystems input-output model was originally proposed by Sraffa (1960), Pasinetti (1973), and

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

Pasinetti (1988) among others. Subsequently, this method was extended to the analysis of pollutant emissions by Treloar (1997) , Ferng (2003), Mongelli et al. (2006), Liang et al. (2007) and Butnar and Llop (2007). In particular, Snchez-Chliz and Duarte (2004) and Machado et al. (2001) 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 can be 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 pollutant goods that count for 14% of emissions. Tarancon et al. (2010) applies the 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 price of emissions.

Our results show that European countries are characterized by very different emission patterns. In particular, Central/Eastern Europe is the most emission-intensive region in both of the years considered in our analysis. At the same time, countries in this region have seen the largest reduction in emission-intensity from 2005 to 2009. As a consequence, a rise in the ETS price will strongly affect these countries as their levels of emissions are the highest in Europe. We also find that the reduction of emission intensities in Central/Eastern European countries was associated with a decrease in their output intensity. 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.

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. Other studies, such as those by 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 and indicates 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 and Section 3 presents the two methods used to decompose sectoral emissions. Section 4 contains the results of the empirical application to the 27 European countries and the price analysis. Section 5 contains the results on the trade in intermediate goods between the EU and China. At the end of the paper we provide some concluding remarks.

2 Data description

The emission 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 emission 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. 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. CO_2 emissions for certain countries are reported as zero in some sectors where it is unlikely that no CO_2 was emitted (for example, 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 in the last decile of the distribution of emission intensity on average in the EU in 2005 and 2009 respectively. The pattern of emission intensity is relatively stable between the two years considered.

Emission intensity, last decile of the distribution, 2005, 2009

[TABLE 1 HERE]

3 Methodology

Our analysis can be divided into two parts: first we use statistical indicators to quantify the importance of the emission intensity for the economies of the EU-27 countries. Second, we apply an input-output decomposition analysis to detect the main drivers of the European emissions. Third, we use the Leontief matrix derived from the input-output analysis to assess the impact of the change in the emission price (ETS) on the different sectors of each one of the 27 EU countries. Finally, we use inter-regional IO tables and environmental accounts to quantify the impact of Chinese intermediate goods exported to Europe. We calculate the emissions embodied in European imports from China and examines how these have changed from 2005 to 2009.

3.1 Statistical indicators

We follow Mendiluce et al. (2010) and Alcntara 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

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

$$\frac{E_i}{Y_i} = \sum \frac{E_{s,i}}{Y_{s,i}} \frac{Y_{s,i}}{Y_i} \tag{1}$$

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 on sectoral GDP. Also in Equation 1, 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.

3.2 Input Output subsystem decomposition and price analysis

3.2.1 Input output decomposition

Having examined the emission intensity of EU countries, we then use the details of the production structure of each economy, as given in the national input-output tables, to decompose sectoral emissions into different channels within the production system. The emission-intensive sectors vary across Europe. We identify three groups of countries (Northern European, Mediterranean and Central/Eastern European countries) in order to find similarities in the emission patterns in 2005 and in 2009. 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 apply the same methodology to 2005 and 2009 and then we compare the results. We follow the price model outlined in Tarancon et al. (2010). The basic equation that describes the linear relationships between the sectors of each country is:

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

Where x is the total output required, γ 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 its 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:

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

Where I is the identity matrix and $(I-A)^{-1}$ is the Leontief 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 elements are given by the amount of CO_2 emitted by each sector to produce one unit monetary output. [2]

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

In which M is the multiplier matrix, which shows the total direct and indirect CO_2 intensities of each sector. In order to disentangle the emission patterns through the different countries, we use Equation 5 to derive a subsystem decomposition. The subsystems approach considers an individual sector (or a group of sectors) as a particular unit that does not modify the main characteristics of the system of which it is a part. Taking into account that a subsystem responds to the notion of an individual sector or group of sectors that produce a specific commodity, an input-output table enables sectors of production to be considered as subsystems. This analysis, which decomposes the emissions produced by each sector into different sources, extends our knowledge about the emission patterns within the production system. Details on the subsystem decomposition equations can be found in Llop and Tol (2011) and in Di Cosmo et al. (2012). This analysis decomposes the economy of each one of the 27 EU countries into four components: a final demand component (divided between domestic demand and exports), an induced component, an external component and an internal component. If we have two subsystems, A and B, the induced component (INCS) comprises the emissions produced by one subsystem due (A) due to demand from a separate subsystem (B); the external component (ECS) is the emissions produced by subsystem B to demand from A; the internal component (ITCS) is the emissions produced by subsystem A due to demand from A; the final-demand-level component is the direct emissions produced due demand for final goods; this comprises both those produced for domestic consumption (DCS) and for export (EXCS).

3.2.2 Price model

The input output model allows us to simulate the effects of the change of the emission price (ETS) on the different sectors. We identify the changes in the cost of different sectors as the result of the changes in the value of the energy inputs. More specifically, we investigate the effects of a rise in the ETS price from €17 to €25 /tonne, both in 2005 and in 2009. We applied exactly the same change in the ETS in both years in order to compare the results. The ETS are applied only to some sectors of the economy, as shown in Table 2.

Sectors with ETS

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

[TABLE 2 HERE]

We assume that all the other sectors are subjected to a carbon tax equal to €1/t CO_2 that is kept constant over time in order to disentangle the effects of the change in the ETS price only. The change of the emission price will have a direct effect on the sectors under the ETS regulation and an indirect effect on the prices of the sectors not directly affected 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. From the supply identity given by Equation 4 the value of the of the output of the country i and in sector s 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:

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

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

$$p_{x_{i,s}} = a_{1,i,s} p_{x_{1,i}} + a_{2,i,s} p_{x_{2,i}} + ... + a_{n,i,s} p_{x_{n,i}} + \delta p_{z_{s,i}} \tag{7}$$

in which $\delta_{s,i}$ is the ratio between the primary input of the sector s and its output, and $p_{x_{i,s}}$ is the price of the good produced by sector s. 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 in the primary sectors. 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:

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

where $l_{qs,i}$ is the element of the column s of the Leontief matrix of the country i. The emission intensity of each sector will determine the impact of the variation of the ETS price on that sector 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 the other goods. Emission intensive sectors or sectors that use as intermediate inputs emission intensive goods will increase in their final costs more than the low emission sectors.

4 Results

4.1 Energy intensity

The indicator of the energy intensity described by Equation 1 may be used to compare the sectoral emissions of the same country. Our analysis shows that all the Central/Eastern European countries have higher levels of emission intensity than that of Northern and Mediterranean European countries. However, 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.

Total emission intensity, 2005 and 2009

[TABLE 3 HERE]

The pattern presented by the Central/Eastern European countries is particularly interesting, as it highlights that the production of emission-intensive goods contracted strongly between 2005 and 2009. It is therefore interesting to disentangle the emissions produced by the ETS sectors to check whether sectors under emission-price regulation perform differently vis-a-vis the other sectors. Table 4 shows the emission and output intensities in the ETS sectors.

Emission intensity and output intensity in ETS sectors, 2005 and 2009

[TABLE 4 HERE]

This table shows that Central/Eastern countries had the strongest reduction in emission intensities in the ETS sectors. Moreover, the reduction of the emissions in the ETS sectors happened jointly with the reduction of the output intensity. Our analysis suggests that the abatement of emissions in the sectors subject to the ETS regulation can be partially ascribed to the ETS pricing adopted in 2009. However, the dynamic of the output intensity highlights that the production intensity of the more polluting sectors has decreased between 2005 and 2009. This implies that the production of polluting goods has been shifted from the Central/Eastern European countries to other countries outside the EU.

4.2 Sectoral analysis and ETS impact

The results of our analysis on energy intensity have shown the specificities of the different European countries. It is important to analyze whether the introduction of ETS in 2005 has changed the performance of the ETS sectors (shown in Table 2) with respect to the other sectors of the economy. [3] The first part of the indicator

[3] In this section of the paper we focus on the ratio between sectoral emissions and sectoral GDP as the statistical analysis gives an immediate measure of the impact of the emission price on sectoral emissions and can be useful to present the different country specificities. As the increase of the ETS will affect also the final prices of the different sectors through direct and indirect effects we will present a detailed analysis of the effects of the variation of the ETS on the economy in Section **??**.

expressed in Equation 1 (the ratio $\frac{E_{s,i}}{Y_{s,i}}$) reflects the sectoral emission intensities across different countries. Thus, we use this indicator to evaluate the sectoral emission intensity of each country in 2005 and in 2009 and compare them. Table 5 shows the average of the differences in the emission intensities between 2005 and 2009 for the EU countries. Column 1 reports the averages for the sectors directly affected by ETS regulation and Column 2 shows the average of the change in emission intensities for all other sectors.

Differences in the average emission intensity (2005,2009), ETS vs other sectors, thousands

[TABLE 5 HERE]

As shown in Table 5, sectors directly affected by ETS have reduced their emission intensity between 2005 to 2009 more than the other sectors. In particular, Central/Eastern European countries show the greatest change in the emission intensity patterns. The explanation of the emission intensity indicator in the Easter European countries is twofold. On one hand the GDP of the Central/Eastern countries 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 values have decreased for all the EU countries, including the Central/Eastern European countries. This second effect may be influenced by the adoption of the emission pricing scheme, as well by the dislocation of the production of highly emission-intensive goods to other countries (such as China). However, the data used in this analysis don't allow us to correctly identify these two effects. Thus, in order to give a partial explanation of the latter effect, we analyze in Section 5 the imports of goods (and thus, embodied emissions) from China.

4.3 Decomposition analysis

The results of the statistical analysis show that the ratio of sectoral emissions to each country's GDP fell between 2005 and 2009. Moreover our results show that, on average, the ratio between sectoral emissions and sectoral GDP has fallen more in the sectors regulated by ETS pricing than all the other sectors of the economy. This result emphasizes that the ETS adopted by the EU may have changed the behavior of the sectors directly affected by the emission prices. [4] Our results show that EU countries are reducing the quantify of CO_2 emitted in the on the production of various goods, as they are mandated to do according to the Kyoto protocol. However, our analysis also highlights that different emission patterns emerge across the EU; as the responsibility for emissions is assigned based on the production of goods in different sectors, it is interesting to determine whether relatively non-polluting countries are importing the polluting goods from the more emission-intensive countries. At the same time, it is interesting to determine whether the EU as a

[4] The data available for our analysis don't allow us to disentangle the sources of the fall in the emissions; their decrease may be ascribed to the adoption of the ETS pricing as well as to the dislocation of part of the production process to other non-European countries

whole is importing the polluting goods from other countries in the world and, in particular, from China. The following paragraphs aim to answer these questions by using an input-output decomposition analysis. First, we investigate whether Central/Eastern European countries consistently export part of their production from sectors classified (see Table 1) as highly emission-intensive, to other EU countries. Second, we investigate the impact of the change of the emission price. Countries with high emissions will be directly affected by the change of the emission price; on the contrary, countries that are net importers of emission-intensive goods will be only indirectly affected through the rise in the price of imported goods. Finally, we analyze the trade dynamics between Europe and China in order to establish the amount of emission intensive goods produced in China which are used by European countries both in their production processes and in final consumption.

4.3.1 I/O analysis: exports

Table 6 shows the percentage of goods exported by countries of the same geographical area (Northern, Mediterranean and Eastern) to the other EU countries by sector and year. In the column Δ there is the difference between the percentage of goods exported between 2005 and 2009. We divided the EU countries by geographical location in order to investigate whether different patterns of exports emerge for countries characterized by different productive structure. Our results show that the net exports from sectors that ,accordingly to Table 1, may be classified as pollutant are higher in the Central/Eastern European countries than in all the other European countries both in 2005 and 2009. However, the Δ column shows that the exports from these sectors fell in Northern countries and increased between 2005 and 2009 in the Central/Eastern countries. This shows that, on average, the production of pollutant goods has decreased in the EU over time. However, our results also show the determinants of this reduction, as the pollution from countries that produce emissions intensive goods has been moved to specific location. From our analysis it emerges that in Europe polluted goods are predominately made by Central/Eastern European countries and exported to other EU countries both as intermediate inputs and final goods. Thus, the UNFCCC definition of environmental responsibility, which assigns responsibility for emissions to the producer and not to the consumer, penalizes Central/Eastern countries more than Northern European countries. Thus, a target based on consumption instead of one based on production would be required to correctly assign the emissions to the countries that demand and use the pollutant goods. The same issue arises when the trade between Europe and China is analyzed. Again, our analysis shows that Kyoto targets have reflected favourably on Europe, as the production of heavily polluting goods decreased between 2005 and 2009. However, as discussed in Section 5 the production of emission-intensive goods may have just shifted from Europe to China. Again, the emissions embedded in the intermediate inputs or final goods imported from China are not not captured by the current emissions trading scheme.

I/O decomposition analysis: exports (2005,2009)

[TABLE 6 HERE]

4.3.2 Effects of ETS variation

Our previous results show that the production of emission-intensive goods is not evenly located across Europe; therefore, the impact of a rise in the ETS price will affect different European countries in different ways. We use Equation 8 to determine the impact of a change in the emission price on different countries and different sectors. Table 7 shows the results for the sectors under ETS regulation, and Table 8 shows the results for all the other sectors. From our analysis it emerges that, as expected, ETS-regulated sectors are more likely to be affected by the price variations than all other sectors. This result holds for all the countries analyzed. 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.

Final price change after the variation of ETS price, ETS sectors (2005,2009)

[TABLE 7 HERE]

Final price change after the variation of ETS price, other sectors (2005,2009)

[TABLE 8 HERE]

5 Intermediate goods from China and CO_2 emissions

The analysis to this point suggests that in general all regions of 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, has 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 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 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. From 2005 to 2009 the value of Chinese intermediates used in the EU production process has increased by 158%; this is in contrast to an increase of 16% and 10% in the value of intermediates imported from the NAFTA [5] and BRIIAT [6] regions respectively, and a reduction of 8% in the value of intermediates imported from East Asia.

5.1 Patterns of emission intensity: Europe and China

The graph below illustrates the relative emissions intensity 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. Emission intensity is calculated as sectoral CO_2 emissions divided by sectoral output.

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

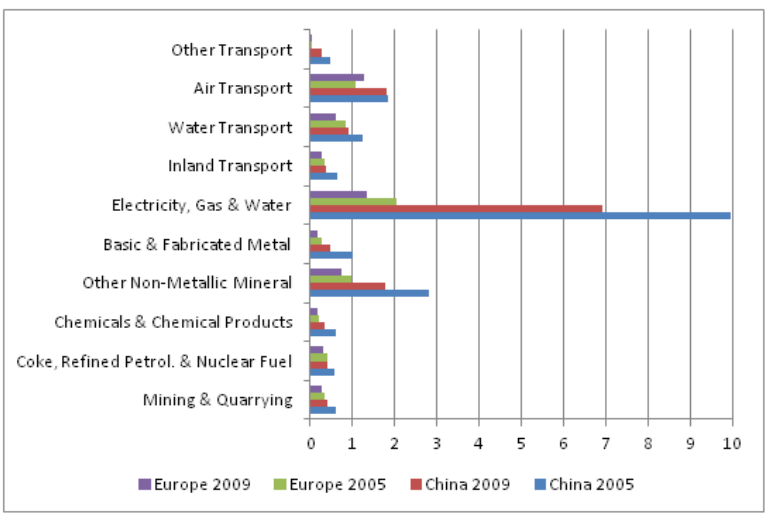


Figure 1 shows that while both regions are reducing the carbon intensity of production, the level of carbon intensity in China remains far above that of Europe; this implies that if intermediate goods, previously produced in Europe, are now being produced in China, global CO_2 emissions driven by the European production process will have risen in a way which is not captured by the producer-pays definition of environmental

[5]the North American Free Trade Agreement
[6]Brazil, Russia, India, Indonesia, Australia and Turkey

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 industries.

Furthermore, Figure 1 shows that using a single region input-output analysis to calculate the embodied 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

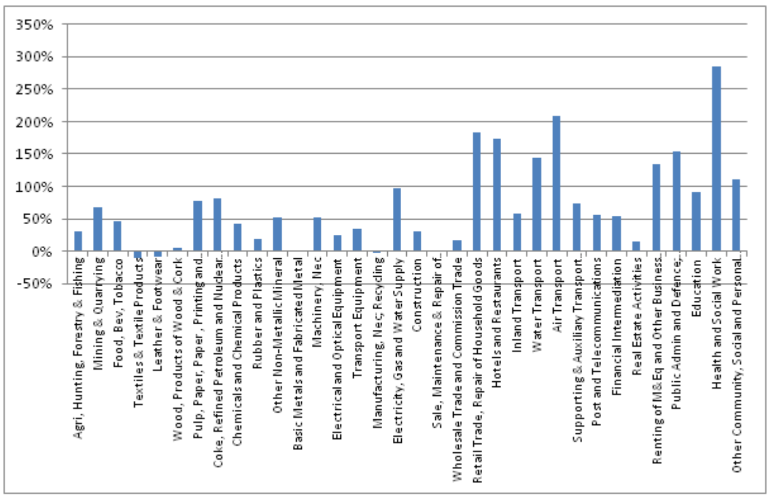
To examine the quantity of intermediate goods which are used in the European production process but produced in China we make use of the Interregional Input-Output tables, available via the World Input-Output Database (WIOD.org). We combined data from the Eurozone and "Other EU" countries to look at 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 imported emissions embodied in the European production process.

Figure 2: The proportion of European inputs sources from China, 2005 and 2009

	2005	2009
Agriculture, Hunting, Forestry and Fishing	0.32%	0.70%
Mining and Quarrying	0.46%	1.05%
Food, Beverages and Tobacco	0.29%	0.66%
Textiles and Textile Products	2.46%	4.55%
Leather, Leather and Footwear	0.92%	1.74%
Wood and Products of Wood and Cork	0.49%	1.00%
Pulp, Paper, Paper , Printing and Publishing	0.38%	0.91%
Coke, Refined Petroleum and Nuclear Fuel	0.19%	0.42%
Chemicals and Chemical Products	0.64%	1.41%
Rubber and Plastics	0.81%	1.84%
Other Non-Metallic Mineral	0.46%	1.04%
Basic Metals and Fabricated Metal	0.69%	1.27%
Machinery, Nec	1.03%	2.39%
Electrical and Optical Equipment	3.63%	7.15%
Transport Equipment	0.84%	1.92%
Manufacturing, Nec; Recycling	0.89%	1.82%
Electricity, Gas and Water Supply	0.35%	0.72%
Construction	0.56%	1.24%
Sale, Maintenance and Repair of Motor Vehicles and Motorcycles; Retail Sale of Fuel	0.44%	1.10%
Wholesale Trade and Commission Trade, Except of Motor Vehicles and Motorcycles	0.58%	1.34%
Retail Trade, Except of Motor Vehicles and Motorcycles; Repair of Household Goods	0.44%	1.11%
Hotels and Restaurants	0.25%	0.60%
Inland Transport	0.39%	0.88%
Water Transport	0.92%	2.24%
Air Transport	0.94%	2.44%
Other Supporting and Auxiliary Transport Activities; Activities of Travel Agencies	0.56%	1.36%
Post and Telecommunications	1.11%	2.74%
Financial Intermediation	0.22%	0.64%
Real Estate Activities	0.25%	0.74%
Renting of M&Eq and Other Business Activities	0.48%	1.20%
Public Admin and Defence; Compulsory Social Security	0.76%	1.84%
Education	0.47%	1.10%
Health and Social Work	0.54%	1.40%
Other Community, Social and Personal Services	0.58%	1.43%

From Figure 2 we can see that, for all sectors analysed, the proportion of intermediate goods sourced from China is quite low, however in all sectors the proportion of Chinese inputs (relative to total inputs) is increasing. In the majority of sectors analysed in our database the proportion of production inputs sourced from China has more than doubled 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 had 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, as illustrated by Figure 3 below.

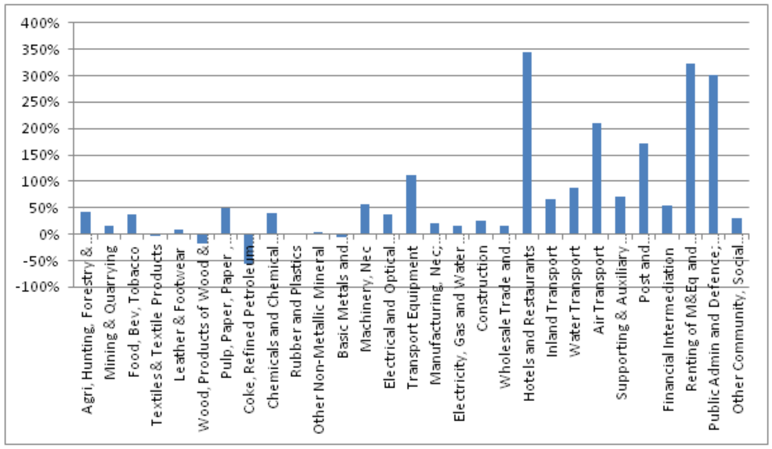
Figure 3: The increase in imported emission embodied in intermediate goods



For some sectors the increase is not particularly large in relative terms, however in absolute terms it can be significant. Looking at the sector producing "other non-metallic mineral products", imports of emissions embodied in intermediates increased by 52% which, while not insignificant, is modest relative to the increase from other sectors. However, looking at the increase in the absolute quantity of embodied CO_2 from this sector, it increased by over 1,000 ktCO_2 . For other sectors the increase in embodied emissions from intermediates is large both in relative and absolute terms. The sector supplying electricity, gas and water experienced an increase in embodied emissions in intermediates of 97% from 2005 to 2009. This near doubling translates to an additional 13,000 tonnes of CO_2 embodied in the intermediate goods imported from China and used by this sector.

While Figure 3 shows that there has been a rise in the embodied emissions 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 permits since they have been introduced, which has been partially driven by an excess supply of ETS certificates (Granados and Carpintero (2013) and Anderson and DiMaria (2011)). The fact that embodied emissions 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.

Figure 4: The increase in imported emission embodied in final goods



Thus far we have focused on the import of embodied emissions in intermediate goods. These are emissions that may be over-looked as, when considering embodied emissions, a more obvious source to look at are the emissions embodied in final goods. Imports of final goods are indeed an important source of embodied emissions, and the WIOD provides us with the data necessary to look at this source of emissions also. Figure 4 shows that the embodied emissions from final goods are also increasing from 2005 to 2009. The graph shows that the percentage increase from 2005 to 2009 is generally less pronounced than was the case for intermediate goods. A further point to note is that there is a large difference in the absolute quantity of emissions embodied in intermediates; the total embodied CO_2 emissions imported from intermediate goods was 31,700kt CO_2 in 2005 and 56,000kt CO_2 in 2009, compared to 16,600kt and 23,100kt of CO_2 respectively imported from final goods.

6 Conclusions

In this paper we analyzed the patterns of CO_2 emissions in Europe both through statistical indicators and through an input-output methodology. Our results show that emissions, in absolute terms, have decreased across Europe from 2005 to 2009. At the same time, our analysis highlights that the patterns of emission intensity (calculated as the ratio of each country's sectoral emissions to GDP) are very different across the EU.

First, the emission intensity decreased more rapidly in the Central/Eastern countries than in all other European countries. Our analysis shows that the abatement of CO_2 emissions in these countries is mainly due to the reduction of emissions in the most pollutant sectors, which are regulated under ETS. In order to disentangle the causes of the emission reduction, we analyzed the output intensities and found that in the Central/Eastern European countries the output of the emission-intensive sectors has decreased together with the emissions. Therefore, our analysis suggests that the pollutant sectors, which are relatively more important in the economies of Central/Eastern EU countries than in the rest of the EU, have decreased their production from 2005 to 2009. 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.

Second, we investigated the dynamics of the exports, in order to find whether the pollution embedded in the goods produced in the Central/Eastern Europwan countries is consumed by these countries or abroad. We follow Llop and Tol (2011) and Di Cosmo et al. (2012) and we use the subsystem decomposition analysis to understand the export dynamics of the EU countries, focusing on the Central/Eastern-Europe region. Our results show that the goods from the pollutant sectors in the Central/Eastern EU countries are mostly exported to the other European countries, in order to be used as intermediate inputs in the production process or as final consumption goods. Thus, our analysis shows that the taxation of the emissions based on production will not be able to reduce the demand for goods with high levels of embodied emissions.

Third, following Tarancon et al. (2010), we used an input-output price model to simulate the effect that a rise in the price of EU-ETS permits, from €17 to €25/tonne, would have on the final price of goods in each EU country and sector. We find that all countries in the EU are reducing the emission-intensity of their production processes from 2005 to 2009, and we find that the reduction is greatest in those sectors regulated under the ETS. Again, Central/Eastern countries are the most strongly affected by this measure, as their emission levels are the highest in Europe.

Finally, in order to investigate whether the reduction of European emissions and output intensity between 2005 to 2009 was associated with the shift in the production of emission-intensive goods from Central/Eastern European countries to non-European countries we examine the importing of intermediate goods between the EU and China. Results show that while emissions embodied in imported intermediate goods have increased from 2005 to 2009, this increase is not limited to, nor particularly notable in, the sectors regulated by the ETS.

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

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 2: Sectors with ETS

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 3: Total emission intensity, 2005 and 2009

	2005	2009	Δ
GB	0.112	0.105	0.007
IE	0.079	0.057	0.022
Germany	0.137	0.108	0.030
France	0.076	0.055	0.021
Sweden	0.073	0.063	0.010
Austria	0.100	0.067	0.033
Belgium	0.128	0.094	0.034
Finland	0.146	0.118	0.029
Luxembourg	0.038	0.022	0.016
NLD	0.140	0.109	0.031
Denmark	0.171	0.143	0.027
Spain	0.131	0.079	0.052
Italy	0.112	0.082	0.030
Cyprus	0.255	0.179	0.076
Greece	0.252	0.192	0.061
Malta	0.201	0.157	0.044
Portugal	0.180	0.120	0.060
Estonia	0.503	0.382	0.121
Slovakia	0.349	0.170	0.179
Slovenia	0.183	0.136	0.047
Poland	0.471	0.318	0.154
Romania	0.490	0.246	0.244
Bulgaria	0.786	0.392	0.393
CHZ	0.341	0.209	0.132
Hungary	0.204	0.159	0.045
Latvia	0.221	0.141	0.080
Lithuania	0.280	0.181	0.099

Table 4: Emission intensity and output intensity in ETS sectors, 2005 and 2009

	Emission intensity			Output intensity		
	2005	2009	Δ	2005	2009	Δ
GB	0.014	0.011	0.003	6.25%	5.52%	0.007
IE	0.012	0.007	0.005	8.36%	7.67%	0.007
Germany	0.015	0.012	0.003	8.24%	7.46%	0.008
France	0.019	0.013	0.006	8.78%	8.58%	0.002
Sweden	0.016	0.014	0.002	9.64%	9.22%	0.004
Austria	0.022	0.016	0.005	9.77%	9.26%	0.005
Belgium	0.026	0.018	0.007	9.70%	8.76%	0.009
Finland	0.031	0.023	0.008	14.44%	12.24%	0.022
Luxembourg	0.011	0.006	0.005	3.69%	2.63%	0.011
NLD	0.023	0.016	0.007	9.48%	8.83%	0.007
Denmark	0.017	0.011	0.006	8.20%	6.75%	0.014
Spain	0.096	0.053	0.043	14.45%	13.66%	0.008
Italy	0.074	0.052	0.022	14.99%	13.79%	0.012
Cyprus	0.178	0.132	0.046	8.65%	8.73%	**-0.001**
Greece	0.188	0.136	0.052	11.92%	11.00%	0.009
Malta	0.149	0.122	0.027	9.98%	10.96%	**-0.010**
Portugal	0.118	0.075	0.043	13.45%	14.20%	**-0.008**
Estonia	0.448	0.334	0.114	11.21%	33.42%	**-0.222**
Slovakia	0.267	0.133	0.134	21.65%	13.31%	0.083
Slovenia	0.130	0.086	0.044	16.78%	8.63%	0.081
Poland	0.371	0.243	0.128	17.11%	24.30%	**-0.072**
Romania	0.352	0.172	0.180	18.73%	17.24%	0.015
Bulgaria	0.645	0.318	0.327	22.07%	31.84%	**-0.098**
CHZ	0.277	0.171	0.107	18.31%	17.07%	0.012
Hungary	0.122	0.093	0.029	15.05%	9.28%	0.058
Latvia	0.099	0.057	0.042	8.95%	5.70%	0.033
Lithuania	0.179	0.110	0.069	19.60%	10.97%	0.086

Table 5: Differences in the average emission intensity (2005,2009), ETS vs other sectors, thousands

	Country	2005	2009
	EU	3.59	0.27
Northern/Central	GB	1.17	-0.05
	IE	2.05	0.27
	Germany	3.38	0.22
	France	1.84	0.29
	Sweden	0.92	0.13
	Austria	3.51	0.29
	Belgium	4.19	0.18
	Finland	2.68	0.35
	Luxembourg	1.33	0.25
	NLD	3.42	0.25
	Denmark	1.95	0.49
Medit	Spain	6.17	0.31
	Italy	3.21	0.28
	Cyprus	6.57	1.07
	Greece	7.50	0.29
	Malta	3.91	0.58
	Portugal	6.15	0.59
Eastern	Estonia	16.31	0.25
	Slovakia	19.10	1.61
	Slovenia	6.26	0.12
	Poland	18.22	0.93
	Romania	25.71	2.29
	Bulgaria	46.70	2.37
	CHZ	15.23	0.92
	Hungary	4.20	0.56
	Latvia	5.93	1.36
	Lithuania	9.90	1.06

Table 6: I/O decomposition analysis: exports (2005,2009

	Northern/Central			Medit.			Eastern		
	2005	2009	Δ	2005	2009	Δ	2005	2009	Δ
Agriculture	12.17%	12.28%	**0.11%**	10.59%	9.95%	-0.64%	12.01%	15.34%	**3.33%**
Mining and Quarying	*11.68%*	*12.30%*	**0.62%**	*5.19%*	*5.76%*	**0.57%**	*0.71%*	*5.02%*	**4.31%**
Food, Beverages and Tobacco	17.33%	17.15%	-0.19%	8.77%	10.05%	**1.28%**	9.81%	11.69%	**1.88%**
Textiles and Textile Products	14.70%	11.95%	-2.75%	16.45%	14.43%	-2.02%	29.90%	23.96%	-5.94%
Leather, Leather and Footware	2.46%	2.16%	-0.30%	7.21%	6.22%	-0.99%	10.20%	8.20%	-2.00%
Wood and Products of Wood and Cork	8.57%	7.44%	-1.13%	4.94%	3.97%	-0.98%	16.14%	13.32%	-2.82%
Pulp, Paper, Printing and Publishing	*16.80%*	*15.61%*	*-1.19%*	*6.54%*	*7.89%*	**1.35%**	*14.72%*	*14.19%*	*-0.54%*
Coke, Refined Petroleum and Nuclear Fuel	*24.47%*	*20.27%*	*-4.20%*	*15.57%*	*12.21%*	*-3.36%*	*11.03%*	*18.64%*	**7.61%**
Chemicals and Chemical Products	*34.07%*	*32.79%*	*-1.28%*	*16.39%*	*15.08%*	*-1.30%*	*32.39%*	*32.77%*	**0.39%**
Rubber and Plastics	14.84%	12.86%	-1.97%	9.45%	9.21%	-0.24%	12.82%	16.26%	**3.44%**
Other Non-Metallic Minerals	*13.08%*	*10.56%*	*-2.52%*	*11.10%*	*8.84%*	*-2.26%*	*17.33%*	*15.50%*	*-1.84%*
Basic Metals and Fabricated Metal	*28.39%*	*25.74%*	*-2.65%*	*13.05%*	*13.21%*	**0.16%**	*33.54%*	*28.70%*	*-4.84%*
Machinery, NEC	12.44%	12.41%	-0.03%	10.30%	10.93%	**0.63%**	18.89%	18.60%	-0.30%
Electrical and Optical Equioment	10.18%	9.82%	-0.36%	5.66%	10.22%	**4.56%**	18.38%	20.78%	**2.41%**
Transport Equipment	7.97%	7.63%	-0.35%	10.08%	8.76%	-1.32%	20.94%	16.62%	-4.32%
Manufacturing, nec; Recycling	11.34%	10.92%	-0.42%	7.49%	6.73%	-0.76%	19.65%	17.57%	-2.09%
Electricity, Gas and Water Supply	*8.37%*	*7.58%*	*-0.79%*	*0.92%*	*1.29%*	**0.37%**	*6.66%*	*8.70%*	*2.04%*
Construction	0.42%	0.36%	-0.06%	0.12%	0.14%	**0.02%**	0.84%	0.80%	-0.04%
Sale of Motor Vehicles and Motorcycles	1.03%	1.26%	**0.23%**	1.69%	1.19%	-0.49%	3.15%	3.93%	**0.78%**
Wholesale Trade and Commission Trade	1.67%	1.47%	-0.20%	0.95%	0.69%	-0.26%	1.47%	1.77%	**0.30%**
Retail Trade	0.22%	0.69%	**0.46%**	0.54%	0.43%	-0.11%	1.17%	1.24%	**0.07%**
Hotels and Restaurants	2.01%	2.18%	**0.17%**	3.61%	3.63%	**0.02%**	2.76%	2.48%	-0.28%
Other Inland Transport	7.98%	8.66%	**0.68%**	9.13%	8.84%	-0.29%	23.27%	24.20%	**0.93%**
Other Water Transport	20.41%	19.58%	-0.83%	19.06%	18.16%	-0.90%	6.49%	7.17%	**0.69%**
Other Air Transport	12.63%	13.16%	0.53%	9.25%	11.00%	**1.75%**	11.74%	10.50%	-1.24%
Supporting Transporting Activities	1.72%	1.68%	-0.03%	1.48%	1.30%	-0.18%	3.37%	3.08%	-0.29%
Post and Telecommunications	1.71%	2.24%	**0.52%**	0.42%	0.40%	-0.02%	1.65%	2.33%	**0.69%**
Financial Intermediation	1.08%	1.44%	**0.35%**	0.19%	0.14%	-0.05%	0.74%	0.69%	-0.05%
Real Estate Activities	0.01%	0.01%	0.00%	0.00%	0.00%	0.00%	0.12%	0.08%	-0.04%
Renting of Machinery and Equipment	1.44%	1.15%	-0.29%	1.33%	0.79%	-0.54%	1.60%	1.53%	-0.07%
Public Admin	0.50%	0.41%	-0.09%	0.21%	0.22%	**0.01%**	0.62%	0.54%	-0.08%
Education	0.47%	0.47%	-0.01%	0.16%	0.16%	0.00%	0.22%	0.19%	-0.03%
Health and Social Work	0.10%	0.09%	0.00%	0.19%	0.19%	0.00%	0.53%	0.83%	**0.30%**
Social and Personal Services	3.61%	3.55%	-0.06%	0.71%	0.54%	-0.17%	2.13%	2.64%	**0.51%**
Private Households with employed p	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Average ETS sectors			-1.72%			-0.64%			**1.02%**
Average other sectors			-0.22%			-0.06%			-0.15%

Note: ETS sectors in italics; in bold the sectors in which the percentage of exports on total production has increased from 2005 to 2009

Table 7: Final price change after the variation of ETS price, ETS sectors (2005,2009

	Northern/Central			Med			Eastern		
	2005	2009	Δ	2005	2009	Δ	2005	2009	Δ
Mining and Quarying	0.27%	0.22%	-0.05%	1.01%	1.02%	**0.01%**	0.64%	0.38%	-0.26%
Pulp, Paper, Printing and Publishing	0.12%	0.10%	-0.02%	0.22%	0.16%	-0.06%	0.39%	0.21%	-0.18%
Coke, Refined Petroleum and Nuclear Fuel	0.33%	0.29%	-0.04%	0.25%	0.39%	**0.14%**	1.20%	1.22%	**0.01%**
Chemicals and Chemical Products	0.17%	0.12%	-0.05%	0.28%	0.19%	-0.10%	1.19%	0.63%	-0.56%
Other Non-Metallic Minerals	0.79%	0.61%	-0.17%	1.25%	0.91%	-0.34%	1.71%	1.09%	-0.62%
Basic Metals and Fabricated Metal	0.29%	0.22%	-0.07%	0.43%	0.73%	**0.30%**	0.84%	0.43%	-0.41%
Electricity, Gas and Water Supply	1.53%	1.11%	-0.42%	3.04%	1.98%	-1.06%	4.61%	2.65%	-1.96%

Table 8: Final price change after the variation of ETS price, other sectors (2005,2009

	Northern/Central			Med			Eastern		
	2005	2009	Δ	2005	2009	Δ	2005	2009	Δ
Agriculture, Hunting, Forestry and Fishing	0.05%	0.04%	-0.01%	0.11%	0.08%	-0.02%	0.15%	0.10%	-0.05%
Food, Beverages and Tobacco	0.04%	0.03%	-0.01%	0.14%	0.11%	-0.03%	0.21%	0.13%	-0.08%
Textiles and Textile Products	0.04%	0.03%	-0.01%	0.14%	0.09%	-0.04%	0.18%	0.11%	-0.07%
Leather, Leather and Footware	0.03%	0.02%	-0.01%	0.11%	0.09%	-0.02%	0.16%	0.09%	-0.07%
Wood and Products of Wood and Cork	0.05%	0.04%	-0.01%	0.11%	0.09%	-0.02%	0.21%	0.13%	-0.07%
Rubber and Plastics	0.05%	0.04%	-0.01%	0.18%	0.14%	-0.04%	0.23%	0.12%	-0.10%
Machinery, NEC	0.05%	0.04%	-0.01%	0.11%	0.10%	-0.02%	0.25%	0.14%	-0.10%
Electrical and Optical Equioment	0.03%	0.02%	-0.01%	0.09%	0.08%	-0.01%	0.15%	0.09%	-0.07%
Transport Equipment	0.04%	0.03%	-0.01%	0.14%	0.11%	-0.03%	0.20%	0.12%	-0.09%
Manufacturing, nec; Recycling	0.05%	0.04%	-0.01%	0.10%	0.09%	-0.02%	0.19%	0.12%	-0.07%
Construction	0.06%	0.05%	-0.01%	0.21%	0.15%	-0.06%	0.22%	0.12%	-0.10%
Sale of Motor Vehicles and Motorcycles	0.03%	0.02%	-0.01%	0.11%	0.07%	-0.04%	0.14%	0.10%	-0.04%
Wholesale Trade and Commission Trade	0.03%	0.02%	-0.01%	0.09%	0.06%	-0.03%	0.11%	0.07%	-0.05%
Retail Trade	0.03%	0.03%	-0.01%	0.10%	0.06%	-0.03%	0.17%	0.10%	-0.07%
Hotels and Restaurants	0.04%	0.03%	-0.01%	0.14%	0.10%	-0.05%	0.19%	0.12%	-0.07%
Other Inland Transport	0.03%	0.02%	-0.01%	0.09%	0.07%	-0.03%	0.17%	0.11%	-0.06%
Other Water Transport	0.02%	0.02%	0.00%	0.06%	0.04%	-0.02%	0.11%	0.08%	-0.04%
Other Air Transport	0.03%	0.02%	0.00%	0.08%	0.05%	-0.02%	0.13%	0.09%	-0.04%
Supporting Transporting Activities	0.03%	0.02%	0.00%	0.11%	0.08%	-0.03%	0.14%	0.09%	-0.05%
Post and Telecommunications	0.02%	0.02%	-0.01%	0.06%	0.06%	0.00%	0.10%	0.07%	-0.04%
Financial Intermediation	0.02%	0.01%	0.00%	0.06%	0.04%	-0.02%	0.08%	0.06%	-0.02%
Real Estate Activities	0.02%	0.02%	0.00%	0.05%	0.03%	-0.02%	0.22%	0.13%	-0.09%
Renting of Machinery and Equipment	0.02%	0.01%	0.00%	0.06%	0.04%	-0.02%	0.13%	0.07%	-0.06%
Public Admin	0.03%	0.02%	0.00%	0.09%	0.07%	-0.02%	0.15%	0.08%	-0.08%
Education	0.02%	0.02%	-0.01%	0.05%	0.04%	-0.01%	0.20%	0.11%	-0.09%
Health and Social Work	0.02%	0.02%	-0.01%	0.06%	0.04%	-0.02%	0.19%	0.10%	-0.09%
Social and Personal Services	0.03%	0.03%	-0.01%	0.12%	0.09%	-0.04%	0.23%	0.13%	-0.09%
Private Households with employed persons	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%

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