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Trade, Energy, and Carbon Dioxide: An Analysis for the Two Economies of Ireland

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Abstract: In this paper we use a subsystem input-output decomposition analysis to examine the drivers of greenhouse gas emissions in the Republic of Ireland and in Northern Ireland. We use a bi-regional input-output analysis to look at how greenhouse gases in one region can be emitted as a result of demand in an exporting region. Looking at emissions generated throughout the island of Ireland, we find that emissions driven by demand in Northern Ireland are larger than those it generates, and vice-versa for the Republic of Ireland. We then use the input-output tables to simulate the effect of imposing a €15/tonne carbon tax in the Republic of Ireland. We find that this causes a decrease in final demand in the Republic of Ireland, and a decrease in output in both the Republic of Ireland and in Northern Ireland; the decrease is greater in the Republic as the domestically produced share of inputs is much larger than the imported share in all sectors.

Key words: Greenhouse gas emissions, Bi-regional input-output analysis, Carbon tax, Republic of Ireland, Northern Ireland
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1. Introduction

Policy measures targeted at one sector in one jurisdiction affect other sectors and jurisdictions through trade. Input-output models describe such interactions. Input-output models, first developed by Leontief (1941), combine transparency and detail with simplicity. For some problems, input-output models are not good enough. For other questions, they provide a useful, first cut at the answer. We here study the propagation of climate policy in the economies of Ireland north and south.

The first application of an input-output model to the environment was undertaken by Leontief in 1970 in which he explained how the environmental externalities of economic activity can be incorporated into a standard input-output model. The first application of Leontief's input-output model to emissions in the Republic of Ireland was undertaken by Bacon (1981), and O'Doherty and Tol in (2007) is a more recent study. The first development of an inter-regional input-output (IRIO) model was by Isard (1951); this paper sets out the framework for adapting Leontief's input-output table to account for inter-sectoral interregional trade. However, Isard (1951) notes the high data requirement and restrictive assumptions on which his model was based, thus a number of simplified versions of the IRIO model have been developed (Liang et al., 2007), and these include the multi-regional input-output (MRIO) model. One of the best known versions of the MRIO model is the Chenery-Moses model; Moses (1955) and Chenery (1953), amongst others[1], independently came up with a method for computing MRIO models which had less restrictive data requirements; according to Hartwick (1971) the Moses-Chenery MRIO model (sometimes referred to as the column-coefficient model) applies known inter-sectoral flows to interregional trade data to compute inter-sectoral interregional coefficients in the MRIO table. Hartwick (1971) notes that: "the information measure of the Isard model is always at least as great as that of the Chenery-Moses model". However, due to the less stringent data requirements of the MRIO model, it is more frequently used than Isard's IRIO model.

In this paper we use an environmental input-output model to analyse the routes through which economic activity leads to energy use and greenhouse gas emissions in the Republic of Ireland and Northern Ireland. Following work done by Llop and Tol (2011), we apply a subsystem decomposition analysis to examine the drivers of greenhouse gas emissions in the Republic of Ireland and Northern Ireland. We focus specifically on the emissions of carbon dioxide, but the appendices to the paper also include an analysis for six other groups

[1] For a more in-depth discussion of these, and other, techniques for estimating multi-regional input-output models see Hartwick (1971) and Okamoto et al. (2005).

of greenhouse gases. We examine trade between the two regions and, following the methodology outlined in Liang et al. (2007), we build a bi-regional input-output model (based on the MRIO model discussed earlier) incorporating the two separate economies on the island of Ireland, which accounts for trade between the two regions. This model allows us to examine how demand for goods in one region leads to energy use and emissions of greenhouse gases in an exporting region.

In the decomposition analysis carried out for the Republic of Ireland by Llop and Tol (2011), the authors found that the source of greenhouse gas emissions is concentrated in a few sectors, but that the sectoral share of emissions depends upon how environmental responsibility is defined. When environmental responsibility accounts for emissions from intermediate inputs, and not just those due final demand, the differences between sectors in terms of emission intensity are less striking. The authors conclude that environmental policies should be designed to take account of emissions from intermediate demand as well as those from final consumption.

In their analysis, Liang et al. (2007) also highlight the importance of the definition of environmental responsibility chosen. In their multi-regional analysis they note the discrepancy between emissions emitted in a region and emissions caused by that region. They note that the definition of responsibility can affect whether or not a given environmental target can be realised. Liang et al. look at a potential revenue-neutral carbon tax and analyse two alternative scenarios: “emitter pays” versus “driver pays”. They find that different regions pay/benefit depending upon the definition of environmental responsibility chosen.

Lenzen et al. (2004) use a multi-regional input-output model to examine how emissions responsibility in five European countries can be embodied in international trade. The authors argue that trade should be taken into account when setting international greenhouse gas abatement targets.

In this paper we use a bi-regional input-output model to examine how greenhouse gas emissions are generated and distributed across the economies of Northern Ireland and the Republic of Ireland. Furthermore, we examine the first-order effects on final demand and production of imposing a carbon tax on fossil fuel combustion in the Republic of Ireland. The paper is structured as follows: Section 2 discusses the methodology of the subsystem decomposition and the bi-regional analysis. Section 3 provides an overview of the data used in the analysis. Section 4 presents the results of the subsystem decomposition of the bi-regional model, and also of the carbon tax analysis. Finally, Section 5 concludes.

2. Methods

2.1. Environmental input-output models

A single-region input-output model works as follows. Goods and services are produced either for consumption or for use in further production. That is,

$$X_1 = X_{1,1} + X_{1,2} + \cdots + X_{1,s} + Y_1$$
$$X_2 = X_{2,1} + X_{2,2} + \cdots + X_{2,s} + Y_2 \tag{1}$$
$$X_s = X_{s,1} + X_{s,2} + \cdots + X_{s,s} + Y_s$$

where X_i is the production of good *i*, and $X_{i,j}$ is the use of good *i* in the production of good *j*; Y_i is the final demand for good *i*. Equation (1) can be rewritten as:

$$X_1 = a_{1,1}X_1 + a_{1,2}X_2 + \cdots + a_{1,s}X_s + Y_1$$
$$X_2 = a_{2,1}X_1 + a_{2,2}X_2 + \cdots + a_{2,s}X_s + Y_2 \tag{2a}$$
$$X_s = a_{s,1}X_1 + a_{s,2}X_2 + \cdots + a_{s,s}X_s + Y_s$$

where:

$$a_{i,j} = \frac{X_{i,j}}{X_j} \tag{2b}$$

In matrix notation,

$$\begin{bmatrix} X_1 \\ X_2 \\ \vdots \\ X_s \end{bmatrix} = \begin{bmatrix} a_{1,1} & a_{1,2} & \cdots & a_{1,s} \\ a_{2,1} & a_{2,2} & \cdots & a_{2,s} \\ \vdots & \vdots & \ddots & \vdots \\ a_{3,1} & a_{s,2} & \cdots & a_{s,s} \end{bmatrix} \begin{bmatrix} X_1 \\ X_2 \\ \vdots \\ X_s \end{bmatrix} + \begin{bmatrix} Y_1 \\ Y_2 \\ \vdots \\ Y_s \end{bmatrix} \tag{2'}$$

Or

$$X = AX + Y \Leftrightarrow (I - A)X = Y \Leftrightarrow X = (I - A)^{-1}Y = LY \tag{2''}$$

Equation (2) specifies how production *X* would respond to a change in demand *Y*, including all intermediate production. *L* is commonly referred to as the Leontief inverse.

Emissions *M* of substance *i* equal

$$M_i = b_{i,1}X_1 + b_{i,2}X_{21} + \cdots + b_{i,s}X_s \forall i = 1,2,\ldots,m \tag{3}$$

where $b_{i,j}$ are the emission coefficients, that is, emission of *i* per unit of production of *j*. In matrix notation,

$$M = BX = BLY \tag{4}$$

Equation (4) relates emissions to production (via *B*) and to final consumption (via *BL*).
Final demand is the sum of household consumption, government consumption, investment, export, and so on. This can be written as

$$Y = \sum_{i=1}^{d} Y_i \Rightarrow M = \sum_{i=1}^{d} M_i = \sum_{i=1}^{d} BLY_i \quad (5)$$

Equation (5) thus attributes emissions *M* to the components of final demand *Y*.

2.2. Bi-regional input-output models

Following the methodology outlined in Liang et al (2006), the basic equation underlying a multiregional input output model is:

$$CAX + CY = X, \quad (6)$$

where *X* and *Y* represent total output and final demand, respectively. *A* represents the technical input-output coefficients in all regions, and C is the matrix of inter-regional trade coefficients. In this paper the multi-regional input-output model refers to a bi-regional model where regions 1 and 2 are the Republic of Ireland and Northern Ireland. In matrix notation:

$$\begin{bmatrix} X_1 \\ X_2 \end{bmatrix} = \begin{bmatrix} C_{11} & C_{12} \\ C_{21} & C_{22} \end{bmatrix} \begin{bmatrix} A_{11} & 0 \\ 0 & A_{22} \end{bmatrix} \begin{bmatrix} X_1 \\ X_2 \end{bmatrix} + \begin{bmatrix} C_{11} & C_{12} \\ C_{21} & C_{22} \end{bmatrix} \begin{bmatrix} Y_1 \\ Y_2 \end{bmatrix} \quad (7)$$

Where C_{12} is the proportion of the output of good *i* in region 1 which was imported from region 2. C_{11} is the proportion which was domestically produced. C_{21} is the proportion of the output of good *i* in region 2 which was imported from region 1, and C_{22} is the proportion which was produced in region 2. For example, say each region (R1 and R2) produces 2 goods, *i* and *j*, the elements of C_{12}would be:

$$\begin{bmatrix} \frac{Imports\ from\ R1\ to\ R2_{Good\ i}}{Total\ Output\ R2_{Good\ i}} & 0 \\ 0 & \frac{Imports\ from\ R1\ to\ R2_{Good\ j}}{Total\ Output\ R2_{Good\ j}} \end{bmatrix}$$

Note that the vector of final demand (CY) now includes intra-industry trade between the two regions. As Equation (6) has the same structure as Equation (2’’), Equations (4) and (5) also apply to a multi-regional input-output model, and the Leontief inverse, B, is now: $(I - CA)^{-1}$.

2.3. Subsystem input-output analysis

Our study involves applying a subsystem input-output decomposition of the sectoral greenhouse gas emissions. The subsystems approach, which captures the channels by which emissions are produced and transmitted throughout the production system, provides useful information about the underlying patterns of emission generation.

The basic idea behind the subsystems approach is that an individual sector (or a group of sectors) can be analysed as a particular unit without modifying the main characteristics of the system of which such particular unit is part. The usefulness of the subsystems approach is that it isolates the relations of an activity from the whole system, and this provides specific information about the production relations of individual units.

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 allows us to consider as subsystems the sectors of production reflected in this table. In this paper we take into account separately all the sectors of production and, for each one, we apply a subsystems division of its greenhouse emissions. This analysis, which decomposes the emissions of each sector into different sources, extends our knowledge about the greenhouse pollution of the production system. We then aggregate the sectors by region and look at how the demand for goods in one region can lead to the emission of greenhouse gases in an exporting region.

The starting point of the subsystems representation consists of the decomposition of the *N* accounts of an input-output system into two categories (*M* and *S*), with 1, 2, …, *m* sectors belonging to *M* subsystem, and *m* + 1, …, *n*, belonging to the *S* subsystem. By taking into account this separation of the accounts, the input-output representation can be written as follows:

$$\begin{pmatrix} A_{MM} & A_{MS} \\ A_{SM} & A_{SS} \end{pmatrix}\begin{pmatrix} x^M \\ x^S \end{pmatrix} + \begin{pmatrix} y^M \\ y^S \end{pmatrix} = \begin{pmatrix} x^M \\ x^S \end{pmatrix} \tag{8}$$

where the subscripts and superscripts denote the group of accounts *M* and *S* respectively. In Equation (8), matrices *A* contain the technical input-output coefficients, the column vector $x = \begin{pmatrix} x^M \\ x^S \end{pmatrix}$ contains the sectoral production and the column vector $y = \begin{pmatrix} y^M \\ y^S \end{pmatrix}$ contains the final demand. From expression (8), we can calculate sectoral production as $x = (I - A)^{-1}y = By$, where *B* is the Leontief inverse. Considering a model which allows for more than one region through *C*, the matrix of inter-regional trade coefficients, the sectoral production equation becomes: $x = (I - CA)^{-1}Cy = BCy$, the Leontief inverse (B) is now $(I - CA)^{-1}$. By taking this definition into account, the model can be written as:

$$\left[\begin{pmatrix} CA_{MM} & CA_{MS} \\ CA_{SM} & CA_{SS} \end{pmatrix}\right]\begin{pmatrix} B_{MM} & B_{MS} \\ B_{SM} & B_{SS} \end{pmatrix}\begin{pmatrix} Cy^M \\ Cy^S \end{pmatrix} + \begin{pmatrix} Cy^M \\ Cy^S \end{pmatrix} = \begin{pmatrix} x^M \\ x^S \end{pmatrix} \tag{9}$$

Expression (9) contains the following two equations:[2]

$$\begin{gathered} CA_{MM}B_{MM}\,Cy^M + CA_{MM}B_{MS}\,Cy^S + CA_{MS}B_{SM}\,Cy^M + CA_{MS}B_{SS}\,Cy^S + Cy^M = x^M, \\ CA_{SS}B_{SM}\,Cy^M + CA_{SS}B_{SS}\,Cy^S + CA_{SM}B_{MM}\,Cy^M + CA_{SM}B_{MS}\,Cy^S + Cy^S = x^S. \end{gathered} \tag{10}$$

The two equations in (10) show the production of the *M* and *S* subsystems, respectively. Let us assume that we are interested in analysing the *S* subsystem. Then, the interpretation of Equation (10) is as follows: The first equation, which defines the total production of *M*, can be divided into two parts. The first one, $CA_{MM}B_{MS}\,Cy^S + CA_{MS}B_{SS}C\,y^S$, shows the effects of the final demand of *S* subsystem on the production of *M* and we can consider it as an *external component*. The remaining elements in the first equation of (10), $CA_{MM}B_{MM}\,Cy^M +$

[2] The related literature usually assumes that the final demand in one subsystem is zero and that means that this subsystem only produces for the intermediate demand (see Alcántara and Padilla (2009)). Differently to the related studies, expression (3) captures all the income relations within the production system.

$CA_{MS}B_{SM}\,Cy^M + Cy^M$, show the production of *M* needed to cover its final demand.[3]

The left hand side of the second equation in expression (10) can be divided into different components that convey different economic meaning. The term $CA_{SS}B_{SM}\,Cy^M + CA_{SM}B_{MM}\,Cy^M$ shows the production of *S* required to cover the final demand of *M* or the *induced component*. The term $CA_{SS}B_{SS}Cy^S + CA_{SM}B_{MS}Cy^S$ is interpreted as an *internal component* that shows effects ending in *S* and starting from *S* as well. Finally, the last component, Cy^S, is the final demand for the *S* subsystem and can be interpreted as a *demand-level component*.

To transform expression (10) into an emissions model, we use matrices E^M and E^S that contain the emission coefficients, calculated as the emissions per unit of production[4] in the *M* and *S* subsystems respectively. These matrices have emissions as rows and sectors as columns. The emissions associated with the components of the *S* subsystem are equal to:

$$EC_S = E^M(CA_{MM}B_{MS} + CA_{MS}B_{SS})Cy^S,$$
$$INC_S = E^S(CA_{SS}B_{SM} + CA_{SM}B_{MM})Cy^M,$$
$$ITC_S = E^S(CA_{SS}B_{SS} + CA_{SM}B_{MS})Cy^S,$$
$$DLC_S = E^S Cy^S$$

These expressions show the emissions associated with the external component (EC_S) – the emissions from subsystem *M* due to demand for *S*; the induced component (INC_S) – the emissions from subsystem *S* due to demand for *M*; the internal component (ITC_S) – the emissions from subsystem *S* due to demand for *S*; and the demand level component (DLC_S) – the direct emissions due to demand for *S*[5]. The total (direct and indirect) emissions (Em_S) of the *S* subsystem can then be calculated as:

$$Em_S = EC_S + INC_S + ITC_S + DLC_S \qquad (11)$$
$$= \underbrace{E^M(CA_{MM}B_{MS} + CA_{MS}B_{SS})Cy^S}_{+\text{external}} + \underbrace{E^S(CA_{SS}B_{SM} + CA_{SM}B_{MM})Cy^M}_{\text{induced}}$$
$$+ \underbrace{E^S(CA_{SS}B_{SS} + CA_{SM}B_{MS})Cy^S}_{\text{internal}} + \underbrace{E^S Cy^S}_{\text{demand}}$$

The subsystem model allows us to analyse the emissions of a sector or group of sectors by disentangling the underlying interdependences within the production system. This extends our knowledge about the effects of particular units of production on the environment.

We should note, however, that the decomposition is not perfect in the sense that the sum of

[3] Note that if we focus on the *S* subsystem, this part of the *M* production does not have any interest.
[4] Measured using gross value-added
[5] Note that a situation of null emissions in *S* (that is, all the elements in E^S equal to zero) means that the INT_S component, the ITC_S component and the DLC_S component are zero. However, the EC_S component can be positive, given that it reflects the emissions of *M* caused by the final demand of *S*.

Em_S and Em_M is greater than the total emissions. Particularly, the induced and external components are doubly counted: $EC_M=INC_S$ and $EC_S=INC_M$. The sum of the induced, internal and demand level components does add up to the total emissions, as does the sum of the external, internal and demand level components. The latter maps all emissions to final demand for S: y^S – we shall therefore refer to this as emissions from consumption. The former maps all emissions from sector S: C^S – we shall therefore refer to this as emissions from production.

3. Data

3.1. Republic of Ireland

The input-output table for the Republic of Ireland is taken from the Central Statistics Office (CSO). Energy statistics by sector and fuel are published by the Sustainable Energy Authority of Ireland. Greenhouse gas emissions by sector and gas are published by the Environmental Protection Agency. The sectors of the three sources are fairly similar, so the concordance tables are straightforward.

3.2. Northern Ireland

There is no input-output table or social accounting matrix available for Northern Ireland. Therefore, we constructed one using data from Northern Ireland where available, and from the Republic of Ireland and the United Kingdom where Northern Ireland data was unavailable.

The following assumptions were made for final demand:

- Relative household consumption per sector in Northern Ireland was set equal to relative consumption in the United Kingdom. That is, we implicitly assumed that consumer prices are uniform in the UK across sectors and regions, and that income elasticities are unity.
- Sectoral consumption by governments and charities in Northern Ireland was also taken from the United Kingdom, and scaled with per capita income.
- The ratio of capital formation and changes in inventories over final consumption in Northern Ireland was set equal to the ratio in the United Kingdom.
- Exports per sector are as observed.
- The ratio of intermediate demand over final consumption in Northern Ireland was set equal to the ratio in the United Kingdom.

The following assumptions were made for production:

- Total inputs equal total outputs.
- Total value added per sector is as observed.
- Total consumption at producers' prices is the difference between the previous two items.
- Imports per sectors are as observed.
- The ratio of intermediate consumption and product taxes less subsidies to total consumption minus imports was set equal to the ratio in the United Kingdom.

The above procedure does not lead to a balanced social accounting matrix. Therefore, we multiplied intermediate demand by β=1.55 and government consumption, charitable consumption, investment, and inventories by 1/β. This factor ensures that total intermediate demand equals total intermediate consumption.

We used the input-output table of the Republic of Ireland as the basis and sectoral intermediate demand and consumption as described above as inputs into the RAS method[6], and so derived an input-output table for Northern Ireland.

Greenhouse gas emissions data for Northern Ireland come from the National Atmospheric Emissions Inventory (NAEI). The NAEI publishes estimates of emissions of carbon dioxide, methane, nitrous oxide, and F-gases (aggregated by their global warming potential) by end user for 1990 and 2003-2007. The data was further downscaled to match the sectors used here on the basis of each sector's share of gross value added (GVA) and the average emission per GVA in that sector for the Republic of Ireland.

3.3. Bilateral trade

Data on bilateral trade were drawn from a report estimating the volume of North/South trade in Ireland (Morgenroth, for InterTrade Ireland, 2009). The sources of the data used in this report are the United Nations Comtrade statistics; which contains detailed data on bilateral trade flows, and the CSO. As the trade data collected for this study was provided at a product rather than a sectoral level, Morgenroth (2009) applies concordance tables to generate data on trade by sector. The trade data for 2005 were used in this analysis.

3.4. Sectors and gases analysed

Table 3.1 below lists the 19 sectors and seven greenhouse gases studied in our analysis.

Table 3.1: Sectors and Greenhouse gases analysed:

Sectors	Greenhouse gases
Agriculture, fishing, forestry	Carbon dioxide from fossil fuel (CO_2 fossil)
Coal, peat, petroleum, metal ores, quarrying	Carbon dioxide – other (CO_2 other)
Food, beverage, tobacco	Methane (CH_4)
Textiles Clothing Leather & Footwear	Nitrous Oxide (N_2O)
Wood & wood products	Perfluorcarbons (PFCs)
Pulp, paper & print production	Halofluorocarbons (HFCs)
Chemical production	Sulphur Hexafluoride (SF_6)
Rubber & plastic production	
Non-metallic mineral production	
Metal prod. excl. machinery & transport equip.	
Agriculture & industrial machinery	
Office and data process machines	

[6] For a detailed discussion of RAS methodology see Parikh, 1979

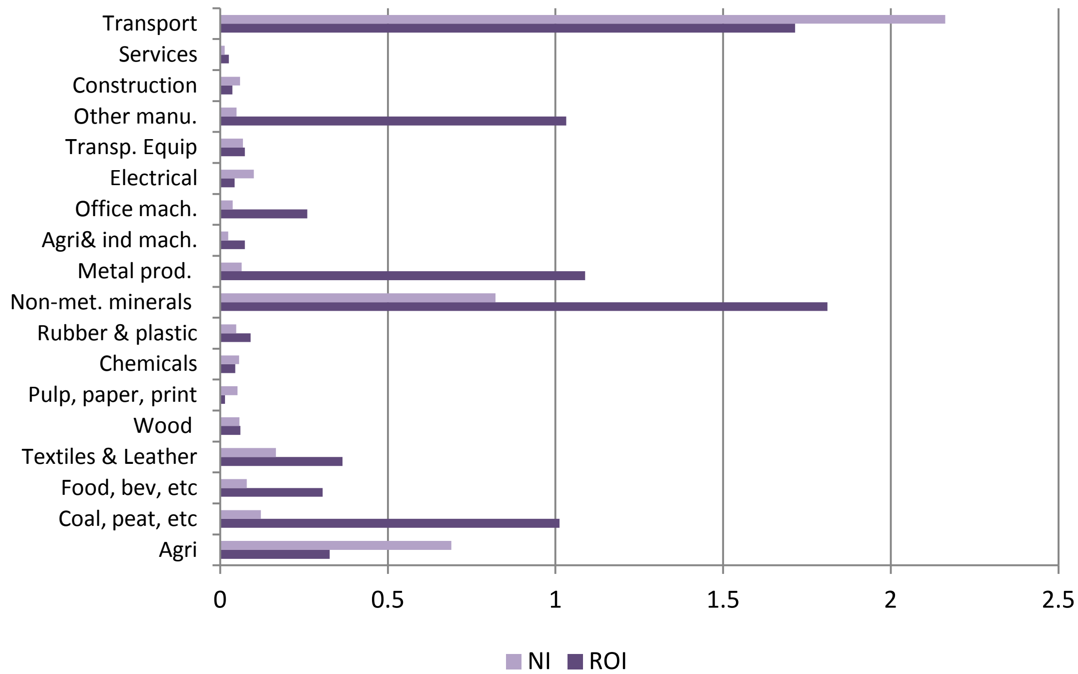
Electrical goods	
Transport equipment	
Other manufacturing	
Fuel, power, water	
Construction	
Services (excl. transport)	
Transport	

4. Results

4.1. Emission Intensity

In order to calculate the emission coefficients for each gas and for each sector, we divided sectoral greenhouse gas emissions (given in the Environmental Accounts) by gross value added per sector. The graphs below show the CO_2 emission intensities per sector. As the "Fuel, Power and Water" sector dwarfs other sectors in terms of emission intensity, results for this sector are reported on a separate graph.

Figure 4.1: CO_2 emissions (in ktCO_2) per unit of gross value added (in millions of €)

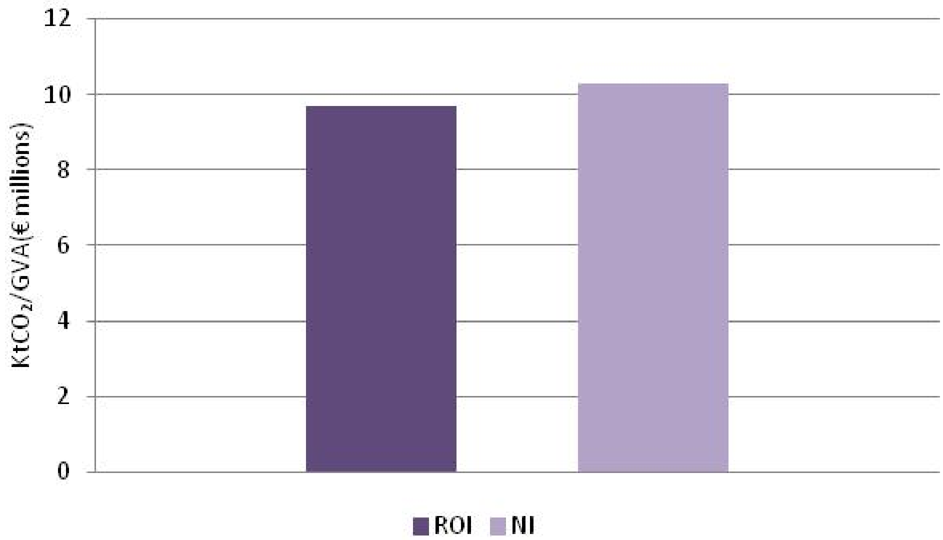


As can been seen from Figure 4.1, the pattern of emission intensity is broadly similar in both regions, with some notable exceptions. In both regions the Transport sector accounts for a large proportion of emissions relative to sectoral value added. Transport is the second most emission intensive sector in the Republic of Ireland and the most emission intensive in Northern Ireland. In both regions the manufacture of non-metallic mineral products is highly emission intensive. Other sectors which are notable for their high level of emissions relative to value-added are the metal production sector and "other manufacturing" in the Republic of Ireland, and the agricultural sector in Northern Ireland. It is clear from Figure 4.1 that while some sectors are highly emission intensive in one region, the corresponding sector in the other region may have a low level of emission intensity; this could be due to a number of factors. It may be due to the fuel mix of the sector, i.e., it may be that a more carbon intensive mix of fuels is being used in one region. It may also be due to the composition of industries within that sector. Finally, it may be due to the method in which aggregate emissions are reported and how these emissions are then divided between sectors. For metal production, the reason is clear: that sector is dominated by energy-intensive aluminium production in the Republic. For “other manufacturing”, probably all three reasons count. Furthermore, data on emissions in the Republic of Ireland are from the EPA while emissions data for Northern Ireland come from the NAEI, both sources present emissions data at different levels of aggregation. As we have energy use data for the Republic of Ireland from the SEAI, we disaggregate emissions, where necessary, based on shares of energy use. Emissions data for Northern Ireland are disaggregated based on shares of value-added.

Sectors which are notable for their low levels of emission intensity are the services sector and the sector manufacturing office and data process machines, in both regions, the manufacture of agricultural and industrial machines in Northern Ireland, and the Pulp, Paper and Print sector in the Republic of Ireland.

In both regions the sector which has by far the highest level of CO_2 emissions relative to value added is the “Fuel, Power and Water” sector, as emissions from this sector dwarf the emissions from other sectors, this is represented on a separate graph.

Figure 4.2: Emission Intensity (ktCO_2 per €million of GVA) for the Fuel, Power and Water sector



As can be seen from Figure 4.2, the emission intensity of the Fuel, Power and Water sector is broadly similar in both regions but somewhat higher in Northern Ireland. This may be due to the underlying fuel mix of this sector; 43 per cent of fuel used in the Fuel, Power and Water sector in Northern Ireland is coal, compared to 26 per cent in the Republic. Furthermore, in this sector in 2005 there were no renewables used in Northern Ireland, whereas in the Republic seven per cent of fuel use came from renewables.

For sectoral emission intensities of the other greenhouse gases analysed, please see the Appendix.

4.2. Decomposition Analysis

Running the decomposition analysis outlined in section 2.3 and applying the emission intensities described above, we get the following results:

CO_2 emissions per sector from production versus consumption:

Figure 4.3: Emissions from Production:

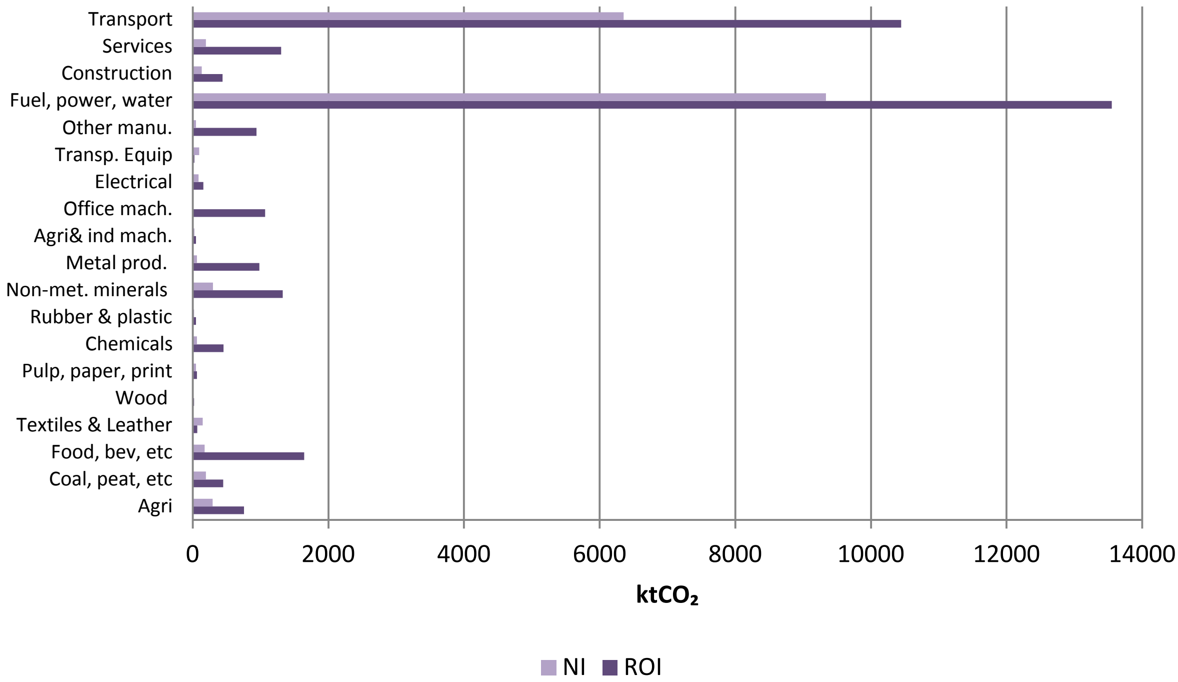
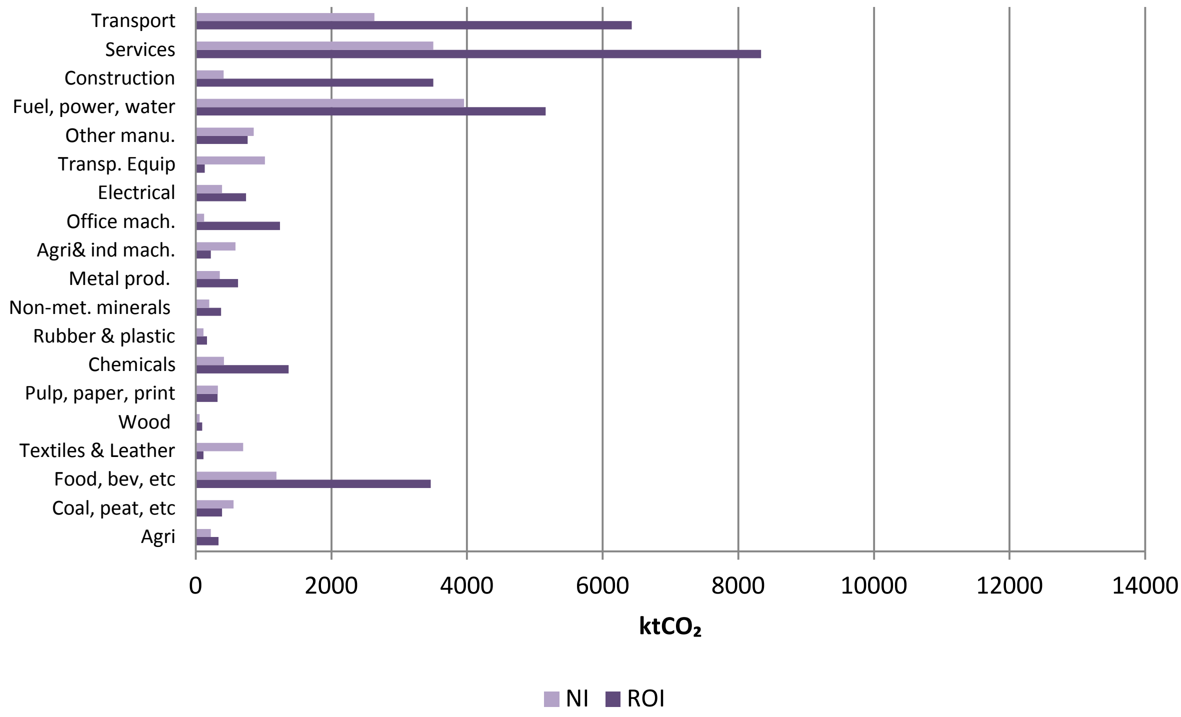


Figure 4.4: Emissions from Consumption:



Applying the subsystem decomposition methodology outlined in Section 2.3, Figures 4.3 and 4.4 above illustrate the breakdown of emissions between consumption (external + internal + demand level components) and production (internal + induced + demand level components). Emissions from production are clearly larger in the Fuel, Power and Water sector and in the Transport sector in both regions. Consumption emissions are small from these sectors as the external component is small. On the other hand we can see that emissions in the Services sector in both regions are largely due to emissions from consumption; the same holds true for Food, Beverages and Tobacco sector. In both these sectors the external component is large while the induced component is small.

Figures 4.3 and 4.4 provide the breakdown for each individual sector when inter-regional trade is accounted for, however, in a bi-regional input-output model it is particularly interesting to look at the emissions data aggregated to a regional level to examine how demand for goods from one region leads to greenhouse gas emissions in an exporting region.

4.3. Bi-regional analysis

Looking at the interactions between emissions in the Republic of Ireland and Northern Ireland, we can see that for the Republic of Ireland, the emissions from production are slightly larger than emission from consumption, while the opposite holds true for Northern Ireland.

Table 4.1: Regional aggregation of sectoral greenhouse gas emissions

	Emissions of CO_2 (000's of tonnes) from:	
	Production	Consumption
ROI	33,797	33,789
NI	17,609	17,618
Total	51,407	51,407

These results show that, on aggregate, Northern Ireland's carbon emissions are lower than they would be in the absence of trade with the Republic of Ireland and, vice versa, emissions in the Republic of Ireland are higher due to trade with Northern Ireland. In other words, emissions driven by demand in Northern Ireland are larger than those it generates, while the opposite holds true for the Republic of Ireland. The differences are minimal, though.

4.4. The impact of a carbon tax

We can use the input-output tables to analyse the impact of a carbon tax in one region on final demand in that region, and on total output in both regions. In the Republic of Ireland a carbon tax was introduced in the 2010 budget at a rate of €15 per tonne CO_2, this tax applies to oil and gas (but not to solid fuels) and to all sectors except those already regulated under the EU's Emissions Trading System (EU-ETS). In our analysis, we look at the effect of applying a carbon tax of €15 per tonne CO_2 to the consumption of all fuels in the Republic of Ireland (including solid fuels, which are mainly used for home heating anyway) and to all sectors except those covered under the EU-ETS, specifically: Fuel, Power and Water; Pulp, Paper and Print; Non-Metallic Mineral Products and; Metal Production excluding machinery and transport equipment.

In order to assess how a carbon tax will affect the final demand for goods from each sector we need to know: (1) the fuel mix of each sector (Table 4.2), (2) the share of energy inputs in the total inputs of each sector (Table 4.3), (3) the carbon intensities of the fuels used (Appendix: Table A7) and, (4) the price of each fuel before the application of the carbon tax (Appendix: Table A8). Assuming that all increases in input costs are passed onto consumers in the form of higher prices, and applying the price elasticities of demand estimated by Lyons et al[7] (2007) (Appendix: Table A9), we can estimate the contraction in the final demand for goods from each sector. This is similar to analysis carried out by Labandeira and Labega (1999) in which they combined input-output analysis with micro-simulation to model the impacts of a carbon tax in Spain.

Given that our input-output model is linear, we can then calculate the new level of output (x^*):

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[7] These elasticities were not estimated for each of the sectors used in this analysis, thus the elasticities were applied according to the best fit.

According to the basic multi-regional input-output equation:

$$CAx + Cy = x \qquad (6)$$

Rearranging, we get:

$$x = (I - CA)^{-1}Cy$$

Following the imposition of the carbon tax *Cy* is now *Cy**[8], thus:

$$x^{*} = (I - CA)^{-1}Cy^{*}$$

This allows us to calculate the change in final demand as Cy-Cy^*, and the change in total output as x-x^*.

[8] Note the part of the vector which refers to final demand in Northern Ireland remains unchanged, it is only the final demand in the Republic that contracts due to the imposition of the carbon tax

Table 4.2: Sectoral fuel mix - ROI

	Gas	Oil[9]	Petrol	Diesel	Coal	Peat	Renew.	Elect.
Agri, etc	0%	0%	0%	84%	0%	0%	0%	16%
Coal, peat…	16%	24%	0%	31%	0%	0%	0%	29%
Food, bev…	34%	19%	0%	6%	9%	0%	9%	23%
Textiles, Leather…	6%	26%	0%	15%	21%	0%	0%	32%
Wood, …	3%	1%	0%	2%	0%	0%	75%	19%
Pulp, paper..	25%	10%	0%	11%	0%	0%	0%	54%
Chemicals	47%	12%	0%	5%	0%	0%	0%	36%
Rubber & plastic	18%	4%	0%	11%	3%	0%	0%	64%
Non-met. minerals	12%	42%	0%	9%	26%	0%	0%	11%
Metal prod.	2%	86%	0%	1%	0%	0%	0%	10%
Agri& ind mach.	36%	15%	0%	6%	2%	0%	0%	41%
Office mach.	15%	33%	0%	5%	0%	0%	0%	46%
Electrical	15%	33%	0%	5%	0%	0%	0%	46%
Transport Equip	35%	13%	0%	7%	0%	0%	0%	45%
Other manu.	8%	24%	0%	13%	1%	0%	0%	54%
Fuel, power, water	38%	14%	0%	1%	26%	9%	7%	5%
Construction	19%	1%	0%	35%	2%	0%	0%	43%
Services	19%	1%	0%	35%	2%	0%	0%	43%
Transport	0%	0%	42%	57%	0%	0%	0%	0%

[9] Includes fuel oil, other oil and LPG

Table 4.3: Energy share of total inputs per sector

Sector	Energy share of inputs
Agri, forestry, fishing	1.36%
Coal, peat, mining	3.13%
Food, bev, tobacco	1.10%
Textiles & Leather	1.26%
Wood, wood products	2.66%
Pulp, paper, print	0.25%
Chemicals	0.52%
Rubber & plastic	2.32%
Non-met. minerals	3.65%
Metal prod.	1.71%
Agri& ind mach.	1.03%
Office mach.	0.05%
Electrical	0.85%
Transport Equip	1.56%
Other manu.	0.67%
Fuel, power, water	22.14%
Construction	0.40%
Services	0.64%
Transport	0.37%

Applying a carbon tax of €15 per tonne CO_2, and imposing the elasticities given in Appendix II, allows us to calculate the contraction in the demand for goods and services in the Republic of Ireland. We have no information on direct imports (cross-border shopping) and thus it is not possible to estimate whether this increase in the price of goods and services in the Republic of Ireland would lead to an increase in the demand for these goods and services in Northern Ireland. Furthermore, in this analysis we are estimating only the first order effects of the carbon tax; we assume that no switching to lower carbon fuels and no substitution of factor inputs take place.

Table 4.4: Change in final demand[10] and total output

Sector	Change in Final Demand ROI (%)	Change in Total Output ROI (%)	Change in Total Output NI (%)
Agri, forestry, fishing	-0.06%	-0.08%	-0.0030%
Coal, peat, mining	-0.05%	-0.03%	-0.0004%
Food, bev, tobacco	-0.10%	-0.09%	-0.0007%
Textiles & Leather	-0.08%	-0.08%	-0.0001%
Wood, wood products	-0.01%	-0.01%	-0.0011%
Pulp, paper, print	0.00%	0.00%	-0.0002%
Chemicals	0.00%	0.00%	-0.0002%
Rubber & plastic	-0.01%	-0.01%	-0.0008%
Non-met. minerals	0.00%	-0.01%	-0.0013%
Metal prod.	0.00%	-0.01%	-0.0003%
Agri& ind mach.	-0.01%	-0.01%	-0.0001%
Office mach.	0.00%	0.00%	-0.0001%
Electrical	-0.01%	-0.01%	0.0000%
Transport Equip	-0.01%	-0.01%	0.0000%
Other manu.	0.00%	-0.01%	-0.0002%
Fuel, power, water	0.00%	-0.02%	-0.0004%
Construction	-0.01%	-0.01%	-0.0001%
Services	-0.02%	-0.02%	-0.0001%
Transport	-0.01%	-0.02%	-0.0002%
TOTAL (% change)	**-0.02%**	-0.02%	-0.0002%
TOTAL (€ change)	**-48,667,259**	**-74,309,751**	**-255,307**

Table 4.4 above shows the contraction in final demand and the resultant contraction in total output, due to the carbon tax. Sectors where the contraction in final demand is the largest are those with a carbon intensive fuel mix and/or those that produce goods which have higher price elasticities of demand. In an input output table, total output is the sum of final demand and the intermediate demand of sectors. Therefore, as final demand falls, there is also a fall in total output. The fall in total output in Northern Ireland is due to a fall in the demand for intermediate goods used to produce final output in the Republic of Ireland. The contraction in demand for intermediate goods is greater in the Republic of Ireland than in Northern Ireland, this is because the domestically produced share of inputs is larger than the imported share in all sectors.

5. Discussion and conclusion

In this paper we decompose the greenhouse gas emissions of the production systems in the Republic of Ireland and Northern Ireland and, using data on inter-regional trade, we examine

[10] No change in final demand in Northern Ireland or in those sectors regulated under EU-ETS

how demand for goods in one region can lead to the emissions of greenhouse gases in an exporting region. Similar to other studies carried out, our results show that when designing environmental policy, whether or not we account for emissions from intermediate consumption matters, and any environmental policy implemented needs to take account of the trade off between "producer pays" and "consumer pays" policies.

In this paper we have shown how certain sectors may be responsible for the emission of substantially more or less greenhouse gases than is commonly attributed to them. In particular, sectors which are responsible for a significant proportion of direct emissions have been shown to be those whose outputs are used as factor inputs in the production of other goods, i.e., those in which the "induced component" is responsible for a large share of emissions. Conversely, certain sectors which are responsible for a low level of direct emissions are driving emissions in other sectors through their demand for emission-intensive intermediate goods.

Finally, we simulated the effects of placing a "producer pays" carbon tax on goods and services produced in the Republic of Ireland and examined how this affects the demand for final goods in this market and the demand for intermediaries in the home market and that of its trading partner. The drop in demand is lower in Northern Ireland as the majority of goods used in the production process are bought in the home market. However, this only reflects the first-order effects of the carbon tax; in the long run companies faced with increased prices in the Republic may chose to source more inputs from Northern Ireland.

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Appendix I: Emission factors and decomposition for CO_2 from fossil fuels:

Table A1: Emission intensities per sector, other greenhouse gases:

	Republic of Ireland						Northern Ireland					
	CO2 (other)	CH4	N20	HFCs	PFCs	SF6	CO2 (other)	CH4	N20	HFCs	PFCs	SF6
Agri, etc	0.00	4.34	2.79	0.00	0.00	0.00	0.00	3.72	3.53	0.00	0.00	0.00
Coal, peat, etc	0.00	0.15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Food, bev, tobacco	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Textiles & Leather	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Wood	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pulp, paper, print	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Chemicals	0.01	0.00	0.00	0.01	0.00	0.00	0.52	0.00	0.00	0.00	0.00	0.00
Rubber & plastic	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Non-met. minerals	2.67	0.01	0.01	0.00	0.00	0.00	0.53	0.00	0.00	0.00	0.00	0.00
Metal prod.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Agri& ind mach.	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Office mach.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Electrical	0.00	0.00	0.00	0.07	0.04	0.02	0.00	0.00	0.00	0.93	0.00	0.05
Transport Equip	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Other manu.	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00
Fuel, power, water	0.00	0.00	0.07	0.00	0.00	0.00	0.00	1.01	0.08	0.00	0.00	0.00
Construction	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Services	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Transport	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00

Table A2: Details of decomposition:

		Emissions from: Production	Emissions from: Consumption
Republic of Ireland	Agri, forestry, fishing	758	336
	Coal, peat, mining	450	386
	Food, bev, tobacco	1,645	3,465
	Textiles & Leather	70	113
	Wood, wood products	22	96
	Pulp, paper, print	63	320
	Chemicals	452	1,369
	Rubber & plastic	47	167
	Non-met. minerals	1,327	372
	Metal prod.	982	623
	Agri& ind mach.	47	225
	Office mach.	1,068	1,241
	Electrical	159	740
	Transport Equip	27	135
	Other manu.	940	766
	Fuel, power, water	13,550	5,162
	Construction	441	3,505
	Services	1,304	8,338
	Transport	10,445	6,430
Northern Ireland	Agri, forestry, fishing	294	224
	Coal, peat, mining	197	559
	Food, bev, tobacco	178	1,188
	Textiles & Leather	149	700
	Wood, wood products	13	57
	Pulp, paper, print	47	327
	Chemicals	65	415
	Rubber & plastic	22	113
	Non-met. minerals	299	200
	Metal prod.	65	355
	Agri& ind mach.	23	585
	Office mach.	11	126
	Electrical	86	387
	Transport Equip	95	1,021
	Other manu.	49	854

	Fuel, power, water	9,336	3,955
	Construction	134	411
	Services	195	3,505
	Transport	6,352	2,636
	TOTAL (ROI + NI)	51,407	51,407

Appendix II: Decomposition analysis for other greenhouse gases:

Table A3: Decomposition for CO_2 other, CH_4 and N_2O:

		CO_2 Other Emissions from:		CH_4 Emissions from:		N_2O Emissions from:	
		Produc.	Consum.	Produc.	Consum.	Produc.	Consum.
Republic of Ireland	Agri, forestry, fishing	0.00	2.50	12057.46	2780.61	7832.73	1807.49
	Coal, peat, mining	0.00	12.81	78.30	39.51	0.00	3.79
	Food, bev,tobacco	0.00	33.14	3.59	7343.54	7.66	4792.96
	Textiles & Leather	0.00	0.45	0.31	3.81	0.49	2.80
	Wood, wood products	0.00	0.71	0.01	92.51	0.21	60.72
	Pulp, paper, print	0.00	5.65	0.05	12.58	0.11	8.71
	Chemicals	71.87	82.75	0.28	73.19	0.63	48.21
	Rubber & plastic	0.00	8.10	0.09	5.12	0.56	4.10
	Non-met. minerals	2092.30	418.24	5.60	4.49	10.02	3.99
	Metal prod.	0.00	6.11	0.01	6.77	0.38	3.56
	Agri& ind mach.	0.00	4.72	0.05	5.78	0.65	4.53
	Office mach.	0.00	2.55	0.19	16.22	6.02	16.23
	Electrical	0.00	9.73	0.03	20.04	0.90	15.64
	Transport Equip	0.00	0.83	0.01	3.21	0.38	2.67
	Other manu.	0.00	24.03	0.49	17.04	1.83	11.35
	Fuel, power, water	0.00	2.83	8.02	10.55	113.96	45.78
	Construction	0.00	1308.56	0.00	349.24	27.01	233.41
	Services	0.00	173.17	871.10	2058.16	79.92	981.71
	Transport	0.00	14.31	25.20	58.77	171.49	123.56
Northern Ireland	Agri, forestry, fishing	0.00	4.82	1896.91	896.28	1816.04	849.44
	Coal, peat, mining	0.00	18.47	0.19	26.98	3.67	12.14
	Food, bev,tobacco	0.00	42.58	0.27	863.01	5.09	746.40
	Textiles & Leather	0.00	18.70	0.11	51.27	2.02	19.86
	Wood, wood products	0.00	1.40	0.03	13.53	0.51	9.72

	Pulp, paper, print	0.00	9.48	0.11	21.67	2.04	9.63
	Chemicals	639.42	287.64	0.13	31.44	2.54	14.43
	Rubber & plastic	0.00	3.30	0.06	11.62	1.07	4.52
	Non-met. minerals	207.35	76.48	0.04	8.69	0.82	2.87
	Metal prod.	0.00	12.69	0.12	26.08	2.28	7.62
	Agri& ind mach.	0.00	20.31	0.06	43.83	1.09	15.78
	Office mach.	0.00	5.10	0.03	10.04	0.53	3.35
	Electrical	0.00	10.55	0.20	24.57	3.89	11.59
	Transport Equip	0.00	73.46	0.17	78.96	3.18	27.19
	Other manu.	0.00	24.54	0.12	64.38	2.32	20.09
	Fuel, power, water	0.00	45.00	1100.32	459.41	85.03	40.56
	Construction	0.00	25.36	0.27	28.95	5.13	15.20
	Services	0.00	150.48	1.16	454.73	17.63	277.21
	Transport	0.00	69.43	8.95	43.45	105.09	56.12
	TOTAL (ROI + NI)	3,010.95	3,010.95	16,060.02	16,060.02	10,314.93	10,314.93

Table A4: Decomposition for HFCs, PFCs and SF_6:

		HFCs Emissions from:		PFCs Emissions from:		SF_6 Emissions from:	
		Produc.	Consum.	Produc.	Consum.	Produc.	Consum.
Republic of Ireland	Agri, forestry, fishing	0.00	0.05	0.00	0.01	0.00	0.05
	Coal, peat, mining	0.00	0.03	0.00	0.02	0.00	0.04
	Food, bev,tobacco	0.00	0.27	0.00	0.13	0.00	0.32
	Textiles & Leather	0.00	0.01	0.00	0.00	0.00	0.01
	Wood, wood products	0.00	0.01	0.00	0.01	0.00	0.02
	Pulp, paper, print	0.00	0.06	0.00	0.03	0.00	0.04
	Chemicals	64.58	63.83	0.00	0.07	0.00	0.09
	Rubber & plastic	0.00	0.03	0.00	0.01	0.00	0.03
	Non-met. minerals	0.00	0.01	0.00	0.01	0.00	0.01
	Metal prod.	0.00	0.03	0.00	0.01	0.00	0.09
	Agri& ind mach.	5.90	5.60	0.00	0.02	0.00	0.02
	Office mach.	0.00	2.63	0.00	2.90	0.00	1.12
	Electrical	146.52	138.33	168.34	158.59	63.68	60.05
	Transport Equip	0.00	0.51	0.00	0.56	0.00	0.22
	Other manu.	0.00	0.05	0.00	0.02	8.51	5.54
	Fuel, power, water	0.00	0.06	0.00	0.04	0.00	0.21
	Construction	0.00	2.54	0.00	2.39	0.03	1.63
	Services	0.00	2.28	0.00	2.01	0.08	1.92
	Transport	0.00	1.18	0.00	1.26	0.00	0.83
Northern Ireland	Agri, forestry, fishing	0.00	0.29	0.00	0.00	0.00	0.02
	Coal, peat, mining	0.00	1.04	0.00	0.00	0.00	0.08
	Food, bev,tobacco	0.00	2.63	0.00	0.00	0.00	0.20
	Textiles & Leather	0.00	1.59	0.00	0.00	0.00	0.12
	Wood, wood products	0.00	0.16	0.00	0.00	0.00	0.01
	Pulp, paper, print	0.00	1.34	0.00	0.00	0.00	0.10
	Chemicals	0.00	1.48	0.00	0.00	0.00	0.11
	Rubber & plastic	0.00	0.31	0.00	0.00	0.00	0.02

	Non-met. minerals	0.00	0.29	0.00	0.00	0.00	0.02
	Metal prod.	0.00	1.10	0.00	0.00	0.00	0.08
	Agri& ind mach.	0.00	3.22	0.00	0.00	0.00	0.25
	Office mach.	0.00	0.59	0.00	0.00	0.00	0.04
	Electrical	472.01	309.98	0.00	0.09	35.09	23.07
	Transport Equip	0.00	72.63	0.00	0.08	0.00	5.42
	Other manu.	0.00	24.06	0.00	0.02	0.00	1.81
	Fuel, power, water	0.00	1.91	0.00	0.00	0.00	0.14
	Construction	0.00	6.51	0.00	0.01	0.00	0.49
	Services	0.00	38.70	0.00	0.04	0.00	2.89
	Transport	0.00	3.65	0.00	0.00	0.00	0.27
	TOTAL (ROI + NI)	689.00	689.00	168.34	168.34	107.38	107.38

Table A5: Bi-regional Analysis for CO_2 other, CH_4 and N_2O:

	CO_2 Other Emissions from:		CH_4 Emissions from:		N_2O Emissions from:	
	Produc.	Consum.	Produc.	Consum.	Produc.	Consum.
ROI	2,164.17	2,111.17	13,050.78	12,901.15	8,254.97	8,171.23
NI	846.77	899.77	3,009.24	3,158.87	2,059.96	2,143.70
Total	3,010.95	3,010.95	16,060.02	16,060.02	10,314.93	10,314.93

Table A6: Bi-regional Analysis for HFCs, PFCs and SF_6:

	HFCs Emissions from:		PFCs Emissions from:		SF_6 Emissions from:	
	Produc.	Consum.	Produc.	Consum.	Produc.	Consum.
ROI	216.99	217.52	168.34	168.08	72.29	72.22
NI	472.01	471.48	0.00	0.26	35.09	35.16
Total	689.00	689.00	168.34	168.34	107.38	107.38

Appendix III: Data used for carbon tax analysis:

Table A7: Carbon intensities of fuels used (expressed as tonnes of CO_2 per TOE)

Fuel	Carbon factor (source: EPA)
Gas	2.3
Fuel Oil	3.069
Petrol	3.069
Diesel	3.069
Coal	3.961
Peat	4.139

Table A8: Fuel prices in 2005. Source: International Energy Agency (IEA) and ESRI Databank[11]

Fuel	Price (per TOE)
Gas	334.53
Fuel Oil	566.55
Petrol	1246.11
Diesel	966.18
Coal	90.34
Peat	144.36

Table A9: Price elasticities of demand for goods from various sectoral groups

Sectoral group	Price elasticity of demand
Food, beverages, tobacco	-0.92
Clothing and footwear	-0.66
Fuels	-0.23
Household equipment	-0.10
Transport & Communication	-0.54
Recreation, entertainment, education	-0.65
Misc. goods & services	-0.06
Housing - rent, repairs, decoration	-0.55

[11] All prices are the price to industry, except for petrol – no petrol is consumed by the industrial sector and therefore the price listed is the price to households. Coal and peat prices are from the ESRI Databank, all others prices are from the IEA.

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