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Domestic Fractions of Emissions in Linked Economies

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Abstract

As our economies become more open and interlinked the regulatory regimes and the implementation of environmental regulations is required to adapt. Going form national economies to linked international economies the regulation of domestic emissions and natural recourses no longer reflects a control over the environmental impact of domestic consumption. This study explores the domestic fraction of environmental impacts generated in a case where two identical economies trade with each other. First a brief introduction to basic input output algebra is given. Then a reformulation of the model for a mirrored economy is derived. Through this the domestic fraction of economic activity generated and the domestic fraction of environmental impacts generated by a unit purchase of a commodity can be found. The suggested framework is then applied to the Norwegian IO tables. The results are presented and discussed in the context of regulatory policy.

Key words: input-output analysis

1 Introduction

Input-output methodology offers a convenient way to assess environmental impacts of various production processes in an economy. The method makes it possible to calculate the complete economic activity generated by a given final demand. In the production of a given commodity the producing industry needs inputs from other industries to its production. The production of those intermediates naturally also requires inputs from

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others, and so on. If one is able to identify all the induced activity, and emission intensities from the various industry sectors are known, the emissions associated with the production of a given commodity can be found.

In increasingly open economies like Norway, where a large part of the industry input and final consumption comes from import, leaving out imports does not provide a good basis for environmental assessment of end use. A convenient way of dealing with this is to assume what is called a mirrored economy. By modelling an economy identical to Norway, with the same technology and production structure, and allowing the two countries trade with each other, we can analyze the environmental repercussions of commodity production in an open economy. When applying this method, one possible approach is to treat the two countries as one. Then, only total emissions from each sector are solved for irrespective of the country in which they occur. This approach does not distinguish between emissions generated domestically and abroad. When a fraction of emissions generated occurs abroad, this has implications for environmental policy making, as national governments will have to cooperate to handle environmental impacts across borders. In this note we will show how the mirrored economy model can be applied to estimate emissions related to imports, and thus generated in the country where the imported goods are produced, not where they are purchased. This goes for intermediate inputs as well as final consumer goods.

2 Input-Output Analysis

Input-output analysis was pioneered by the late Nobel Laureate Wassily Leontief. His book Leontief (1966a) gives a good introduction to the field. He also explored the use of the input-output framework to analyze environmental repercussions of the economy in his article (Leontief, 1970). This work initiated a series of publication on the subject including (Flick, 1974; Leontief, 1974; Steenge, 1978; Moore, 1981; Lee, 1982). Later work on environmental input output assessment includes (Duchin and Lange, 1984; Lave et al., 1995; Lenzen, 2001; Pan and Kraines, 2001; Matthews and Small, 2001; Norris, 2002). Recommended background literature on input-output analysis includes: (Leontief, 1966a; RE. Miller, 1985; Ciaschini, 1988; Peterson, 1991; UN, 1999).

3 The Make and Use framework

National accounts track the make and use of commodities by different sectors in the economy. The Use table describes which products are being used as inputs in the various industries. The Make table shows the output of products from the various industries. By manipulating these tables a symmetric inter industry or inter product coefficient matrix can be obtained. It is separated between inputs from imports and domestic production, and between output that is exported and consumed within the country. The following notations are used:

m	Number of products	
n	Number of industries	
U_d	The use matrix - domestic intermediate	(m, n)
U_i	The use matrix - import intermediate	(m, n)
M_d	the make matrix - domestic intermediate and final	(m, n)
M_e	the make matrix - export intermediate and final	(m, n)
$g_d = M_d'i$	industry intermediate and final output vector	(n)
$q_d = M_d i$	product intermediate and final output vector	(m)
$g_e = Me'i$	industry export intermediate and final output vector	(n)
$q_e = Mei$	product export intermediate and final output vector	(m)
$g_t = g_d + g_e$	industry total intermediate and final output vector	(n)
$q_t = q_d + q_e$	product total intermediate and final output vector	(m)

Based on these matrices the input structure matrix, the market share matrix and the input structure matrix can be generated. The input structure matrix shows input of different intermediate products to any industry divided by the industry's total output, or the Use matrix on coefficient form. This matrix is split into the import and domestic input structure matrices, to distinguish between imported and domestically produced inputs. The market share matrix gives us the production of any commodity from a given industry relative to the total output of the product in the economy, or the industry's market share for that product. The output structure matrix gives us the production of any commodity from a given industry relative to the total output of that industry.

$B_d = U_d \hat{g_t}^{-1}$	the domestic intermediate input structure matrix	(m, n)
$C_d = M_d \hat{g_t}^{-1}$	the domestic output structure matrix	(m, n)
$D_d = M_d' \hat{q_t}^{-1}$	the domestic market share matrix	(n, m)
$B_i = U_i \hat{g_t}^{-1}$	the import intermediate input structure matrix	(m, n)
$C_e = M_e \hat{g_t}^{-1}$	the export output structure matrix	(m, n)
$D_e = M_e' \hat{q_t}^{-1}$	the export market share matrix	(n, m)
$B_t = (U_d + U_i) \hat{g_t}^{-1}$	the total intermediate input structure matrix	(m, n)
$C_t = (M_e + M_d) \hat{g_t}^{-1}$	the total output structure matrix	(m, n)
$D_t = (M_e + M_d)' \hat{q_t}^{-1}$	the total market share matrix	(n, m)

From these matrices a industry by industry or a product by product input-output coefficient matrix can be derived based on the commodity technology or the industry technology assumption. Under the industry technology assumption, the product by product matrix is given by

$$A_{IT} = BD \tag{1}$$

The coefficient matrix A describes products required to produce other products. It is obtained by multiplying the input structure of the different industries producing the demanded commodity by their market shares for that product. This implies, that each industry has a given input structure irrespective of the kind of commodity they are asked to produce. The input structure, i.e. technology, follows the industry, not the product.

When applying the commodity technology assumption, the input structure belongs to the product. The inputs required by a given industry is the sum of the inputs required to produce all of its products. Identical products have identical inputs, as given by the A-matrix. When these input requirements are multiplied by the output of each product from the different industries, each industry's input requirements are found. This is expressed as,

$$B = A_{CT}C \tag{2}$$

Further, solving for the A matrix, we reformulate the formula accordingly to equation 3.

$$A_{CT} = C^{-1}B \tag{3}$$

As can be seen from the expression, we have to invert the output structure matrix to find the input-output coefficient matrix when the commodity-technology assumption is applied. Unfortunately, this requires that the industry-product matrices be square, which they are generally not, unless we make them so by aggregation.

The industry-technology assumption implies that an industry uses the same technology to produce different products. The more intuitive commodity-technology assumption says that one commodity will be produced using the same technology in different industries. In other words, we have to choose whether technology belongs to the industry or the commodity, since most products are being produced in several industries, and most industries deliver more than one product. One serious problem with the first assumption is that it would mean identical production cost for different products sold at different prices which is economically nonsensical given free competition. Hence, the commodity-technology assumption is generally preferred from a theoretical point of view. Practical problems with matrix inversion will, however, normally make this approach difficult to apply, and for our purpose the industry-technology assumption is used for convenience, as is often the case in national accounts. UN (1999). For thorough discussions on the choice of models see ten Raa et al. (1984) and Jansen and ten Raa (1990).

Commodity technology:

$$
\begin{array}{lll}
A_{CT,d} = B_d C_t^{-1} & \text{product by product - domestic} & (m,m) \\
A_{CT,d} = C_t^{-1} B_d & \text{industry by industry - domestic} & (n,n) \\
A_{CT,i} = B_i C_t^{-1} & \text{product by product - import} & (m,m) \\
A_{CT,i} = C_t^{-1} B_i & \text{industry by industry - import} & (n,n) \\
A_{CT,i} = B_t C_t^{-1} & \text{product by product -total} & (m,m) \\
A_{CT,i} = C_t^{-1} B_t & \text{industry by industry - total} & (n,n)
\end{array}
$$

Industry Technology:

$$
\begin{array}{lll}
A_{IT,d} = B_d D_t & \text{product by product - domestic} & (m,m) \\
A_{IT,d} = D_t B_d & \text{industry by industry - domestic} & (n,n) \\
A_{IT,i} = B_i D_t & \text{product by product - import} & (m,m) \\
A_{IT,i} = D_t B_i & \text{industry by industry - import} & (n,n) \\
A_{IT,t} = B_t D_t & \text{product by product - total} & (m,m) \\
A_{IT,t} = D_t B_t & \text{industry by industry - total} & (n,n)
\end{array}
$$

4 The Basic Algebra of Input-output Analysis

Having introduced the make-and-use framework, this section deals with the basic algebra of input-output analysis. It is here shown how the generated A coefficient matrix, from the previous section, section can be used to calculate induced industry activities, product flows and emissions for a given initial demand of products. In the following system of equations, as described by Leontief (1966b), y_i is the final demand of a given product. The coefficients a_{ij} are the requirements of product i to produce a unit of product j. The x_i elements represent the production volume of product i.

$$
\begin{aligned}
a_{11}x_1 + a_{12}x_2 + a_{13}x_3 + y_1 = x_1 \\
a_{21}x_1 + a_{22}x_2 + a_{23}x_3 + y_2 = x_2 \\
a_{31}x_1 + a_{32}x_2 + a_{33}x_3 + y_3 = x_3
\end{aligned}
\tag{4}
$$

This system can be represented on matrix form:

$$\begin{bmatrix} a_{1,1} & a_{1,2} & a_{1,3} \\ a_{2,1} & a_{2,2} & a_{2,3} \\ a_{3,1} & a_{3,2} & a_{3,3} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} + \begin{bmatrix} y_1 \\ y_2 \\ y_3 \end{bmatrix} = \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} \tag{5}$$

The equations can then simply be written as,

$$Ax + y = x \tag{6}$$

where x is the industry output, y is the sum of the final demand and Ax is the required input to the production, the intermediate demand. Solving for x to find the resulting industry output for a given demand y gives

$$(I - A)x = y \Leftrightarrow x = (I - A)^{-1}y \tag{7}$$

Depending on wither the A matrix is an industry by industry or an product by product matrix, x represents respectively the activity in a given sector or the production volume of a given product to achieve a certain final demand y. It should be noted that the $(I - A)^{-1}$ matrix is known as the Leontief inverse.

5 Trade - Introducing Imports and Exports

A general equation for an economy with imports and exports can be derived and expressed as in equation 8. The total availability of goods to the economy is the sum of the domestic industry output x plus the imported commodities m. The consumption side of the economy is given by: The intermediate demand of domestically produced commodities in domestic production $A_d x_d$, the intermediate demand of imported goods and services in domestic production $A_i x_d$, domestic final demand of domestically produced commodities y_d, domestic final demand of imported commodities y_m, and export of domestically produced commodities e. Here, d denotes domestic and m denotes imported.

$$x + m = A_d x + A_m x + y_m + y_d + e \tag{8}$$

In a case where we have two economies trading with each other, each of them described by equation 8, we assume that the import from one economy is equal to the export from the other economy. To simplify the example we assume that the two economies are identical.

Assume that the final consumption within the economy is of final products generated within the economy. Also assume that the export, represented by e, only are intermediate products thus also import is only intermediate products, That is $y_m = 0$. By doing so, we get the following set of equations describing the economic flows between and in the economies.

$$\begin{aligned} x_1 + m_1 &= A_d x_1 + A_m x_1 + e_1 + y_{1,d} \\ x_2 + m_2 &= A_d x_2 + A_m x_2 + e_2 + y_{2,d} \\ e_1 = m_2 &= A_m x_{2,d} \\ e_2 = m_1 &= A_m x_{1,d} \end{aligned} \tag{9}$$

Eliminating the e terms by m and solving

$$\begin{aligned} x_1 &= A_d x_1 + m_2 + y_{1,d} \\ x_2 &= A_d x_2 + m_1 + y_{2,d} \\ m_{1,i} - A_m x_1 &= 0 \\ m_{2,i} - A_m x_2 &= 0 \end{aligned} \tag{10}$$

Can now eliminate m_1 and m_2, but keep them to maintain resolution. Further sort the terms and represent the set of equations on matrix form.

$$\begin{bmatrix} I - A_d & & -I & \\ -A_m & I & & \\ & & I & -A_m \\ & -I & & I - A_d \end{bmatrix} \begin{bmatrix} x_{1,d} \\ m_1 \\ m_2 \\ x_{2,d} \end{bmatrix} = \begin{bmatrix} y_{1,d} \\ 0 \\ 0 \\ y_{2,d} \end{bmatrix} \tag{11}$$

Solving for x-vector to find the output from the domestic production and the import for the two countries for a given demand.

$$\begin{bmatrix} I - A_d & & -I & \\ -A_m & I & & \\ & & I & -A_m \\ & -I & & I - A_d \end{bmatrix}^{-1} \begin{bmatrix} y_{1,d} \\ 0 \\ 0 \\ y_{2,d} \end{bmatrix} = \begin{bmatrix} x_{1,d} \\ m_1 \\ m_2 \\ x_{2,d} \end{bmatrix} \tag{12}$$

The next step is to expand the set of equations to include terms that will allow for the determination of environmental repercussions. First the stressor matrix S, with the dimensions emissions(e) x industries(n), containing the emissions intensities for each industry is introduced. The vector, h, containing the total amount of each compound emitted can then be calculated.

$$h = S(I - A)^{-1}y \tag{13}$$

Further the impact assessment is introduced. In this study characterization of emissions and resource is done following (Guinee, 2002). The structure of matrix W, with the dimensions impact category(c) x emissions(e), containing the characterization factors is shown in Eq. 14. See appendix C for assessment nomenclature.

$$W = \begin{bmatrix} W_{raw,ADP} & \dots & W_{namt,ADP} \\ . & . & . \\ . & . & . \\ . & . & . \\ W_{raw,EP} & \dots & W_{namt,EP} \end{bmatrix} \tag{14}$$

The vector f containing the set of indicators can then generally be found as follows

$$f = WS(I - A)^{-1}y \tag{15}$$

Introducing this to our system of equations, the expansion to include the repercussion of environmental impacts in the two economies can be can be written as follows

$$\begin{bmatrix} W_1 & & & \\ & 0 & & \\ & & 0 & \\ & & & W_2 \end{bmatrix} \begin{bmatrix} B_1 & & & \\ & 0 & & \\ & & 0 & \\ & & & B_2 \end{bmatrix} \begin{bmatrix} I - A_d & & -I & \\ -A_m & I & & \\ & & I & -A_m \\ & -I & & I - A_d \end{bmatrix}^{-1} \begin{bmatrix} y_{1,d} \\ m_1 \\ m_2 \\ y_{2,d} \end{bmatrix} = \begin{bmatrix} f_1 \\ 0 \\ 0 \\ f_2 \end{bmatrix} \tag{16}$$

For region 1, the domestic fraction of total economic activity, θ_n is given by.

$$\theta_n = x_1(\hat{x}_1 + \hat{x}_2)^{-1} \tag{17}$$

To find the domestic fraction of total economic activity generated in the various sectors for the purchase of a given commodity the Market share matrix is applied.

$$\theta_m = D\theta_n \tag{18}$$

The domestic fraction of emissions, θ_e are analogously derived as follows.

$$\{\theta_e\}_{e,n} = \{S\hat{x}_1\}_{e,n}\{S(\hat{x}_1 + \hat{x}_2)\}_{e,n}^{-1} \tag{19}$$

Finally the domestic fraction of impacts can be found

$$\{\theta_c\}_{c,n} = \{WS\hat{x}_1\}_{c,n}\{WS(\hat{x}_1 + \hat{x}_2)\}_{c,n}^{-1} \tag{20}$$

6 Empirical example

The Norwegian IO tables, at the MSG aggregation level (see appendix A and B) from 97 with emission intensities form the same year, are here used to exemplify what information can be found by using the formulation suggested in this note. Due to the high aggregation level, only 42 sectors by 63 commodities, the commodity technology assumption is difficult to use due to real differences in production technology within the aggregated commodity groups. The industry technology assumption is therefore applied in this case. For our purpose it was convenient to aggregate the system further to a 40 sector by 54 commodities.

We have here assumed two identical Norwegian economies trading with each other. This allows investigate the implications of the mirrored economy assumption with respect to the the domestic fraction of total economic activity and of total impacts generated.

In this case, we want to find the induced activity and impacts in both regions as a result of a final demand in one region. Following 21 for the industry technology assumption to find the impacts we get

$$\begin{bmatrix} W & & & \\ & 0 & & \\ & & 0 & \\ & & & W \end{bmatrix} \begin{bmatrix} B & & & \\ & 0 & & \\ & & 0 & \\ & & & B \end{bmatrix} \begin{bmatrix} I - D_t B_d & -I & & \\ -D_t B_m & I & & \\ & & I & -D_t B_m \\ & & -I & I - D_t B_d \end{bmatrix}^{-1} \begin{bmatrix} y_{1,d} \\ 0 \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} f_1 \\ 0 \\ 0 \\ f_2 \end{bmatrix} \tag{21}$$

$$y_m = D y_n \tag{22}$$

The emission intensities for the MSG input-output matrices are on a sector basis and the final demand is on a commodity basis. One option to deal with this is to find the corresponding industry demand to a given commodity demand for use with an industry-by-industry matrix.

This is done in Eq. 22 showing the multiplication of sub-matrix S_c with the market share matrix D to find the S_n matrix containing the industry demand. From this a new S matrix containing S_s with purchases from industries can be assembled as shown in Eq. **??**.

7 Results

In equations 17 and 18 the domestic fractions of total economic activity generated is given. These fractions describes how much of the activity related to the demand from one industry or of commodity is generated in domestic sectors and how much is generated in the corresponding sectors of the other economy.

These fractions are calculated for the 54 commodities in this study and are displayed graphically in figure 1. The commodities are found along the x-axis and the sectors are found along the the y-axis. The dark brow color represents a high fraction of domestic activity while dark blue represents the opposite. To find the domestic fraction profile of a given domestically produced commodity, start at the commodity axis, pick a given commodity number and move then parallel to the industry axis.

The dark line that goes from the lower right corner to the upper left is a consequence of our assumption of no direct imports to consumption. So this analysis only assesses the domestic fractions of goods and services produced in Norway. As the figure shows, many commodities has roughly the same share of imported inputs across industries and, to an ever higher degree, many industries have about the same import shares irrespective of commodities produced. The latter result is partly a consequence of the industry - technology assumption. The government administration sectors have, not surprisingly, a low import share, while production of metals and ships typically has a high fraction of imported inputs.

In equation 17 the fraction of potential impacts are described. The assessment method applied here is developed at the CML center at the university in Leiden and categorizes the various emissions into 10 categories of which eight are shown here. GWP- global warming potential, in CO_2 equivalents. Human, freshwater, marine and terrestrial toxicity potentials in 1.4 di-clorobezene equivalents. Photochemical ozone creation potential in ethene equivalents. Acidification potential in SO_2 equivalents and eutrophication in PO_4^- equivalents. More detailed description on the characterization and assessment method can be found in the CML guide by Guinee (2002).

The emissions accounted for here are only emission of Kyoto gases including NO_x and SO_2, heavy metals, PAH, and particles.

In table 4 the domestic fraction of impacts generated by a unit purchase of a selected set of commodities are listed. The mean and standard deviation for each impact category is listed at the bottom of the table and for each commodity at the far right of the table.

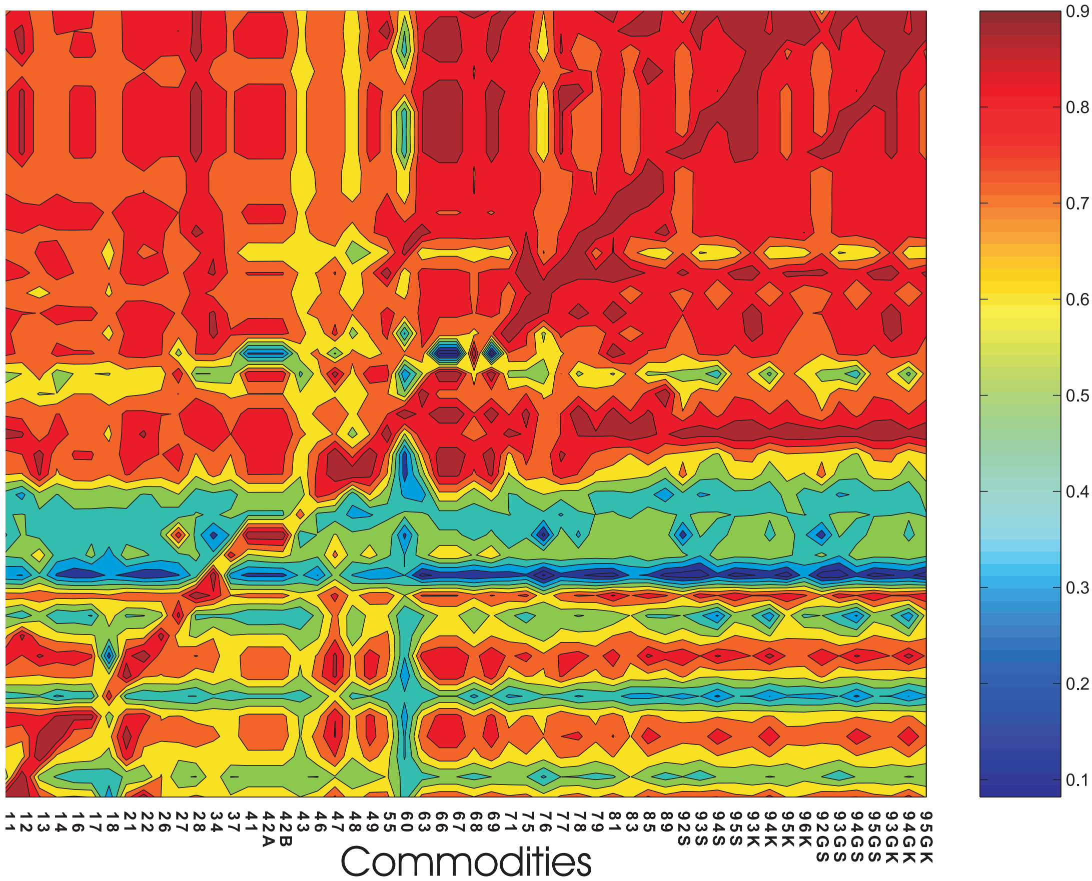

Fig. 1. Domestic fraction total economic activity generated

For the average commodity 75 percent of the Global warming emissions generated in the Norwegian economy occurs domestically. However the domestic fraction of toxic impacts is lower. Up to 40 percent is generated abroad. The photochemical ozone creation potential is found to have the highest domestic fraction of 77 percent. While both Acidification and Eutrophication impacts both have a domestic fraction of around 70 percent. The standard deviation across all impact categories varies from 0.10 to 0.13 which is in the order of 1/5 to 1/7 of the mean value. The variation in the domestic impact fraction for each commodity across all impact categories varies from 0.45 at the lowest, for ships, up to 0.89 for agricultural commodities. However the average commodity across all impact categories has a domestic impact fraction of 0.68 with a standard deviation of 0.11.

Table 4
Domestic fraction of impacts generated

	GWP	HTTP	FAETP	MAETP	TAETP	PCOP	AP	EP	Mean	Sd
Agricultural	0.93	0.91	0.91	0.80	0.71	0.91	0.97	0.98	0.89	0.09
Forestry	0.86	0.75	0.75	0.75	0.78	0.95	0.90	0.97	0.84	0.09
Fishing	0.95	0.80	0.81	0.87	0.92	0.96	0.90	0.81	0.88	0.07
Fish Farms	0.65	0.58	0.58	0.57	0.59	0.69	0.67	0.70	0.63	0.06
Processed Grains,Fruits,Veg.	0.66	0.61	0.61	0.58	0.60	0.66	0.69	0.71	0.64	0.05
Beverages and Tobacco	0.67	0.60	0.60	0.58	0.60	0.67	0.68	0.70	0.64	0.04
Textiles and Apparel	0.49	0.48	0.48	0.49	0.54	0.47	0.42	0.32	0.46	0.06
Processed Fishing	0.82	0.67	0.68	0.76	0.80	0.83	0.81	0.75	0.76	0.06
Meat and Dairy Products	0.89	0.86	0.86	0.73	0.65	0.88	0.95	0.97	0.85	0.11
Wood and Wood Products	0.76	0.58	0.61	0.85	0.86	0.87	0.70	0.69	0.74	0.11
Chemical and Mineral	0.74	0.53	0.53	0.61	0.70	0.62	0.67	0.64	0.63	0.07
Printing and Publishing	0.65	0.55	0.55	0.54	0.55	0.71	0.60	0.72	0.61	0.07
Pulp and Paper Articles	0.80	0.67	0.77	0.96	0.97	0.86	0.86	0.67	0.82	0.12
Industrial Chemicals	0.84	0.75	0.75	0.78	0.74	0.86	0.85	0.80	0.80	0.05
Gasoline	0.92	0.56	0.56	0.59	0.60	0.88	0.93	0.69	0.72	0.17
Diesel Oil	0.92	0.56	0.56	0.59	0.60	0.88	0.93	0.70	0.72	0.16
Fuel Oils etc.	0.92	0.56	0.56	0.60	0.60	0.88	0.93	0.70	0.72	0.16
Metals	0.74	0.77	0.77	0.76	0.76	0.71	0.74	0.60	0.73	0.06
Machinery and Equipment	0.52	0.49	0.49	0.48	0.48	0.56	0.51	0.64	0.52	0.05
Repair	0.68	0.49	0.49	0.52	0.53	0.70	0.65	0.81	0.61	0.12
Ships	0.46	0.38	0.38	0.40	0.40	0.53	0.44	0.62	0.45	0.08
Oil Production Platforms	0.55	0.41	0.41	0.42	0.43	0.61	0.53	0.74	0.51	0.12
Construction	0.68	0.52	0.52	0.57	0.60	0.72	0.60	0.73	0.62	0.08
Ocean Transport	0.50	0.55	0.56	0.57	0.61	0.55	0.49	0.44	0.53	0.05
Finance and Insurance	0.67	0.55	0.55	0.54	0.55	0.82	0.64	0.75	0.63	0.11
Crude Oil	0.96	0.57	0.58	0.64	0.69	0.88	0.72	0.77	0.72	0.14
Natural Gas	0.96	0.57	0.58	0.64	0.69	0.88	0.72	0.77	0.72	0.14
Oil and Gas Exploration	0.88	0.76	0.76	0.71	0.77	0.84	0.77	0.70	0.77	0.06
Oil and Gas Pipeline Transp.	0.96	0.57	0.58	0.64	0.69	0.88	0.72	0.77	0.72	0.14
Electricity	0.68	0.55	0.55	0.55	0.57	0.72	0.60	0.71	0.62	0.08
Road Transport etc.	0.93	0.89	0.89	0.88	0.90	0.96	0.81	0.81	0.88	0.05
Air Transport etc.	0.80	0.62	0.61	0.46	0.47	0.74	0.51	0.65	0.61	0.12
Railways and Tramways	0.62	0.43	0.43	0.45	0.48	0.65	0.53	0.71	0.54	0.11
Water Transport	0.95	0.84	0.84	0.88	0.92	0.92	0.92	0.75	0.88	0.07
Postal and Telecom.	0.68	0.54	0.54	0.51	0.51	0.87	0.61	0.74	0.62	0.13
Toal mean	0.75	0.60	0.61	0.63	0.65	0.77	0.69	0.73	0.68	0.09
Total Sd	0.13	0.12	0.12	0.13	0.13	0.12	0.13	0.10	0.11	0.03

8 Discussion

As our economies become more open and interlinked, the regulatory regimes and the implimentation of environmental regulations is required to adapt. Going from closed economies to linked international economies the regulation of domestic emissions and natural recourses not longer reflect a control over the environmental impact of domestic consumption. In this study we have found that on average about 70% of the impacts for a unit purchase of domestically produced commodities occurs domestically. This might not seem too bad from a regulatory perspective, since only 30 % of the impacts across categories occurs abroad. However, these results need to be interpreted with care. First, when assuming away final consumption of imports, implying that all final goods are produced domestically, we underestimate the fraction of total emissions generated abroad by domestic demand. When a final good is purchased in the home country, we assume that the last stage of production is always carried out domestically. This assumption is used to keep the model simple, and because we do not have the data to assess what fraction of imports goes to final consumption. In real life, however, many products are of course finished abroad. Second, the application of the mirrored economy assumption on Norwegian data gives very conservative estimates with respect to environmental impacts related to imports. It is well known that most environmental impacts occur as a result of energy transformation processes. The Norwegian economy is in this respect very special since 100% of the electricity production is hydropower. There will obviously be rather moderate emissions associated with imports from a country with an extremely low carbon intensive energy sector. This is clearly not the case for the major economies that Norway import goods from, and the industry structure of those economies and their production sectors' emission intensities will naturally differ from the Norwegian one. This situation is investigated for China, Norway and Japan by Hertwich et al. (2002).

The results of this simple model can therefore be considered as a low conservative estimate of impacts generated by import of intermediate inputs to domestic production. Our aim has been to illustrate the method for assessing environmental repercussions generated by trade, and where the impacts are likely to occur. In reality the fraction of impacts generated is obviously larger than our estimates show, which makes the problem even more serious when it comes to policy control over emissions. Based on this we encourage further empirical work on the relationship between emissions and trade, and on establishing regulatory mechanisms for national governments to be able to control the sustainability of domestic consumption.

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A MSG Commodity Codes and Names

11	Agricultural Commodities
12	Commodities from Forestry
13	Commodities from Fishing
14	Commodities from Fish Farms
16	Processed Commodities of Grains, Fruits and Vegetables
17	Beverages and Tobacco
18	Textiles and Apparel
21	Processed Commodities from Fishing
22	Manufactured Meat and Dairy Products
26	Wood and Wood Products
27	Chemical and Mineral Products
28	Commoditities from Printing and Publishing
34	Pulp and Paper Articles
37	Industrial Chemicals
41	Gasoline
42A	Diesel Oil
42B	Fuel Oils etc.
43	Metals
46	Metal Products, Machinery and Equipment
47	Repair
48	Ships
49	Offshore Platforms
55	Construction
60	Ocean Transport
63	Finance and Insurance Services
66	Crude Oil
67	Natural Gas
68	Oil and Gas Exploration and Drilling, Leasing of Oil Drilling Rigs
69	Oil and Gas Pipeline Transport
71	Electricity
75	Road Transport etc.
76	Air Transport etc.
77	Transport by Railways and Tramways
78	Coastal and Inland Water Transport
79	Postal and Telecommunication Services
81	Wholesale, Retail Trade and Transport Margins
83	Dwelling Services
85	Other Private Services
89	Imputed Service Charges from Financial Institutions
92S	Fees Charged on Defence Services
93S	Fees Charged on Education Services
94S	Fees Charged on Health and Veterinary Services etc.
95S	Fees Charged on Other Public Services
93K	Fees Charged on Education Services
94K	Fees Charged on Health and Veterinary Services etc.
95K	Fees Charged on Other Public Services
96K	Fees Charged on Water Supply and Sanitary Services
92GS	Government Consumption, Defence Services
93GS	Government Consumption, Central Government Education
94GS	Government Consumption, Central Government Health-Care and Veterinary Services etc.
95GS	Government Consumption, Production of Other Public Services in Central Government
93GK	Government Consumption, Local Government Education
94GK	Government Consumption, Local Government Health-Care and Veterinary Services etc.
95GK	Government Consumption, Production of Other Public Services in Local Government

B MSG Industry Codes and Names

11	Production of Agricultural Commodities
12	Production of Commodities from Forestry
13	Commodities from Fishery
14	Production of Commodities from Fish Farms
15	Production of Processed Commodities from Grains, Fruits and Vegetables 1517 Production of Beverages and Tobacco
18	Production of Textiles and Wearing Apparels
21	Production of Processed Commodities Fishery
22	Manufacturing of Meat and Dairy Products
26	Manufacturing of Wood and Wood Products
27	Manufacturing of Chemical and Mineral Products
28	Printing and Publishing
34	Production of Pulp and Paper Articles
37	Production of of Industrial Chemicals
40	Refining of Gasoline 4042A Refining of Diesel oil 4042 B Refining of Fuel oils
43	Production of Metals
45	Production of Metal Products, Machinery and Equipment
48	Production of Ships
49	Production of Oil Production Platforms
55	Construction
60	Ocean Transport
63	Production of Finance and Insurance Services
64	Production and Repair Services in Production and Pipeline Transport of Oil and Gas
68	Oil and Gas Exploration and Drilling
71	Production of Electricity
75	Road Transport etc.
76	Air Transport etc.
77	Transport by Railways and Tramways
78	Coastal and Inland Water Transport
79	Postal and Telecommunication Services
81	Wholesale and Retail Trade
83	Production of Dwelling Services
85	Production of Other Private Services
92S	Defence
93S	Central Government Education
94S	Central Government Health-Care etc.
95S	Other Central Government Services
93K	Local Government Education
94K	Local Government Health-Care etc.
95K	Other Local Government Services exclusive of Construction Services
96K	Water Supply and Sanitary Services

C Assessment Nomenclature

Table C.1
Environmental assessment indicators nomenclature

ADP	Abiotic Depletion Potential	Sn-eq.
GWP	Global Warming Potential	CO_2-eq.
ODP	Ozone Depletion Potential	CFC-11-eq.
HTP	Human Toxicity Potential	1.4-DCB-eq.
FAETP	Fresh-Water Aquatic Eco-Toxicity Potential	1.4-DCB-eq.
MAETP	Marine Aquatic Eco-Toxicity Potential	1.4-DCB-eq.
TAETP	Terrestial Eco-Toxicity Potential	1.4-DCB-eq.
PCOP	Photochemical Ozone Creation Potential	C_2H_2-eq.
AP	Acidification Potential	SO_2-eq.
EP	Eutrophication Potential	PO_4^--eq.

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