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AND PUBLIC DEMANDS IN A SMALL OPEN ECONOMY: RESULTS
FROM A SAM-BASED NEO-CLASSICAL LINEAR ATTRIBUTION
SYSTEM FOR SCOTLAND**

BY

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Attribution of Pollution Generation to Local Private and Public Demands in a Small Open Economy: Results from a SAM-Based Neo-Classical Linear Attribution System for Scotland

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1. Introduction

For the construction of environmental accounts, Input Output (IO) systems have a number of clear advantages. First IO is an internally consistency, rigorous accounting framework. Second, the characteristics of IO systems are well known. Third, IO systems focus on the link between intermediate and final demands, and can attribute the indirect, intermediate use of commodities to elements of final demand.

However, there are concerns over the degree of appropriateness of the standard IO attribution approaches (McGregor et al, 2001a). If standard Type I output–pollution multiplier, especially in the case of a very open economy such as Scotland, responsibility for much pollution can be attributed to external sources of demand. Furthermore, when Type II output–pollution multipliers are utilised, local private consumption virtually disappears as a pollution source. This seems to be at variance with the common environmental approach, which would wish to place domestic consumption at the centre of pollution attribution.

In McGregor et al (2001a) we develop the neo-classical linear attribution system (NCLAS) in an IO context in a study of the Jersey economy. The NCLAS approach endogenises the trade accounts so that essentially the economy exports in order to import and the pollutants associated with the production of exports are attributed to imports. However, the endogenisation of final demand sectors is rather crudely done in an IO framework. In this paper we therefore extend the NCLAS approach to a Social Accounting Matrix based analysis for Scotland for 1999.

Section 2 discusses pollution attribution in an IO context, and introduces the concept of the neo-classical linear attribution system (NCLAS). In this section it is argued that the endogenisation of the trade and capital accounts can be better in a Social Accounting Matrix (SAM) rather than IO context. Section 3 discusses the structure of 1999 the environmental SAM that we construct for Scotland. Section 4 outlines the analytics of the SAM NCLAS attribution system and Section 5 reports the results for Scotland. CO₂ is the particular pollutant considered and CO₂ intensities are calculated

for the consumption of individual commodities and between different domestic consumption types. Section 6 is a short conclusion.

2. Pollution Attribution in an Input-Output Context

It is a standard environmental approach to attempt to attribute pollution to elements of final consumption. That is, to attribute direct and indirect pollution generation not to production of commodities but to the consumption that drives that production. An example is the “ecological footprint” concept (Van den Bergh and Verbruggen, 1999). The Input-Output (IO) methods, which account for the use of commodities as intermediate inputs, would seem ideal for this approach (Leontief, 1970). In particular, the accompanying multiplier methods, which link total production to exogenous final demands, would appear particularly suited to act as the basis for such a pollution attribution method. Examples of the conventional use of IO for pollution attribution are Lenzen (1998) and McGregor *et al* (2001b).

However, there are two main problems with the standard IO techniques (Turner, 2002). The first is that with an attribution system based around Type I multipliers, responsibility for pollution is partly attributed to external sources of final demand – exports. This will be especially the case in an open, regional economy, such as Scotland. Furthermore, when Type II multipliers are utilised, local private consumption almost entirely disappears as a driver of local pollution generation.¹ A second problem concerns imports. If pollution attribution is to be made to consumption in the way suggested by the “ecological footprint” approach, a lot of information is required concerning imports which typically is not available in standard IO accounts.

These issues are discussed in detail in Turner (2002) and McGregor *et al* (2001a), where a neo-classical linear attribution system (NCLAS) is suggested. In such an attribution method, the export and investment elements of final demand are endogenised. This means that pollution generation within a given economy is then

¹ In McGregor *et al* (2001a) some pollution generation is still attributed to household consumption, even where Type II multipliers are used. This is because wage income is lower than household

attributed solely to local consumption in that economy. Further, the pollutants generated in the production of exports are attributed to the users of imports for intermediate or final demand.

But within an IO context the methods for the endogenisation of final demand expenditures are of necessity crude. This is because the IO tables do not fully account for these expenditures. For example, it is conventional in the generation of Type II multipliers to endogenise household expenditure by linking it in a linear way to wage income. However, in this kind of approach, household consumption should be linked to household income, but household income has a number of other sources, apart from wage income. In the case of the NCLAS attribution, it is the external and capital accounts that require more detailed treatment. In this paper we therefore use the more extensive Social Accounting Matrix (SAM) as the basis for the attribution.

3. The Structure of the Environmental SAM

A SAM is a particular representation of the macro and meso economic accounts of a socio-economic system, which capture the transactions and transfers between all economic agents in the system (Pyatt and Round, 1985; Reinert and Roland-Holst, 1997). In common with other economic accounting systems it records transactions taking place during a particular accounting period, usually one year. The main features of a SAM are as follows.

First, the accounts are represented as a square matrix; where the incomings and outgoings for each account are shown as a corresponding row and column of the matrix. The transactions are shown in the cells, so the matrix displays the interconnections between agents in an explicit way. Second, the SAM is comprehensive, in the sense that it portrays all the economic activities of the system (consumption, production, accumulation and distribution), although not necessarily in equivalent detail. Thirdly, the SAM is flexible (Thorbecke, 2001), in that, although it is usually set up in a standard, basic framework, there is a large measure of flexibility

expenditure in this set of IO accounts so that some household expenditure was there treated as exogenous.

both in the degree of disaggregation and in the emphasis placed on different parts of the economic system.

A Social Accounting Matrix (SAM) provides a more complete picture of the economy than a conventional I-O account. In particular, it more explicitly tracks market and non-market income and resource flows. The Scottish SAM developed here expands upon an existing Scottish IO table disaggregated to identify separately environmentally sensitive sectors. Highly pollution- or resource-intensive sectors, such as agriculture, electricity generation,² gas, coal, transport and oil processing are therefore separately reported. Appendix 1 details the production sectors aggregation employed.

The SAM framework includes additional accounts for income from employment, corporate, capital and government, together with a set of explicit household accounts (with 5 groups of increasing wealth). The SAM therefore clearly shows the linkage between income distribution and economic structure, which the IO does not.

In structure, the 1999 environmental SAM for Scotland comprises 24 rows (equating to sales) and columns (equating to purchases) representing production sectors. It also incorporates 19 other accounts, again structured to form an equal number of rows and column.

Apart from the production sectors, there are a number of other types of accounts: factors, institutions, foreign and capital accounts. The factor accounts are disaggregated into labour and capital, and labour further separated into five income groups. There are several accounts for ‘institutions’ (Round, 1995), including corporate, government and household accounts. The household accounts are again disaggregated into income quintiles. The foreign account is divided into imports from and exports to the Rest of the UK (RUK) and Rest of the World (ROW) and for each location there are separate trade and income transfer accounts. Tourism is included within the traded sectors so that the RUK and ROW ‘traded’ sectors are adjusted to account for RUK and ROW tourism.

In the SAM, columns detail expenditure from that account while the corresponding row represents payments into the account. For each account, total expenditures and total receipts balance. The accounts therefore chart the flow of income and, in this sense, represent a single circular flow. For example, production sectors (such as agriculture) pay factors of production such as labour for services rendered. This in turn represents income for institutions (such as government, households and firms) Expenditures by institutions determine the demand for goods and services and payments into the capital and foreign account and so on. The complete Scottish SAM for 1999 is shown in Appendix 2.

4. SAM CO₂ Pollution Attribution

In a conventional SAM, it is customary to consider the government, foreign and the capital accounts as exogenous and the factors-of-production, institutions and production-activities accounts as endogenous. As with IO analysis, whether the household account is assumed exogenous or not distinguishes the Type I and Type II multiplier approaches. However, as argued in Section 2 above, for pollution attribution we adopt a neo-classical (NCLAS), rather than a standard Keynesian, approach and endogenise the trade accounts. We also endogenise the capital account. This method therefore identifies domestic consumption as the ultimate source of domestic pollution.

In using the SAM accounts for pollution attribution, we are assuming that certain accounts can be allocated as exogenous. For the endogenous components of the SAM accounts, the following partitioned matrix of average expenditure propensities or coefficients can be constructed.

$$S = \begin{bmatrix} S_{11} & 0 & S_{13} \\ S_{21} & 0 & 0 \\ 0 & S_{32} & S_{33} \end{bmatrix} \quad (1)$$

The matrix S_{11} is the set of Input–Output coefficients reflecting the value of non – primary inputs per unit of each production sectors activity output. The matrix S_{21} represents the value of primary inputs per unit of each production sector’s activity

output. These correspond to the set of coefficients in the value added rows of the IO accounts. In the environmental model the coefficients of the subset S_{13} show the value of each commodity purchased by the foreign and capital sectors for each unit of expenditure from those accounts. The coefficients of the matrix S_{33} show the value of income transfers to the foreign and capital sectors per unit of income from those accounts. Finally, the matrix S_{32} shows the proportion of each unit earned by each type of resource that is allocated to the foreign and capital accounts.

If there are n endogenous accounts and f exogenous accounts, then given the definition of the $n \times n$ matrix S , it follows that the $n \times f$ matrix of endogenous incomes (Y) can be expressed as:

$$Y = SY + F \quad (2)$$

where F is the $n \times f$ matrix of exogenous expenditures with element f_{ij} equal the payment to endogenous account i from exogenous account j , and the element y_{ij} of matrix Y as the income of account i directly or indirectly attributed to expenditure from exogenous account j .

This corresponds to the analogous IO procedure. However, in this case, several sub-matrices will show no transactions within the SAM and will be recorded as zeros. Through elementary matrix manipulation, equation (2) can be rewritten as:

$$Y = [1 - S]^{-1} F \quad (3)$$

Again, this is the familiar multiplier equation where $[1-S]^{-1}$ is the SAM multiplier matrix, analogous to the Leontief inverse of a conventional IO system. Here, the matrix of endogenous income Y (i.e. production activity incomes, Y_1 ; factor incomes, Y_2 and institution incomes, Y_3) can be derived by pre-multiplying the matrix of exogenous expenditures, F , by a multiplier matrix $[1-S]^{-1}$. This matrix is referred to as the ‘accounting multiplier matrix’ (Thorbecke, 1998) because it accounts for the results represented in a SAM and not the process by which these results are generated. According to Round (2003, p. 14-6) it is ‘more precisely, a matrix of accounting

multipliers'. While IO multipliers capture only inter-industry effects, SAM-based multipliers account for not only direct and indirect effects but also induced effects on factor and household incomes and activity outputs due to the (Keynesian) income – expenditure multipliers (Robinson, 1989; Adleman and Robinson, 1989).

What is being undertaken here is a SAM attribution-pollution analysis using the NCLAS approach so that local household and public accounts are exogenous. Within these exogenous accounts, households are broken down into five income bands. In the SAM attribution method we identify pollution as being essentially generated by the use of commodities as intermediate inputs or as final consumption (McGregor *et al*, 2001a). We begin by considering the matrix of pollutants generated by the use of commodities as intermediate inputs in production, $P^{S,I,N}$. In the context of the NCLAS attribution, this is the indirect and induced pollutants associated with the production of the commodities that enter the exogenous domestic consumption accounts.

$$P^{S,I,N} = B^I (1 - S^N)^{-1} \Phi F_C^D \quad (4)$$

where $P^{S,I,N}$ is a $p \times c$ matrix, where element $p^{S,I,N}_{ij}$ is the amount of pollutant i generated by one unit of expenditure in exogenous domestic consumption account j , B^I is a $p \times n$ matrix of direct pollution coefficients, where the element b^I_{ij} is the amount of pollutant i directly generated by one unit of expenditure in account j , Φ is the $n \times c$ matrix of exogenous expenditure coefficients, where element ϕ_{ij} is the expenditures on account i , per unit of exogenous domestic consumption expenditure j . F_C^D is a $c \times c$ diagonal matrix where the i th diagonal element is the total expenditure in exogenous domestic consumption account i .

Two important points should be made about the matrix B^I . The first is that direct pollution generated in the production of a particular commodity depends upon not only the pollution associated with the use of domestically produced goods as inputs, but also of imported goods. For example, where production requires the combustion of imported fuel, the pollution is directly associated with the production of that commodity. This means that we require information on the import use in particular

sectors, where that import use is disaggregated by commodity type. This information is more detailed than is often supplied with an IO tables and SAM.³

Second, some of the endogenised non-production accounts, in particular investment expenditure and tourist elements of export expenditure, might have direct pollution coefficients. For Scotland, tourist final demand expenditure is separately identified in the IO table so that we have generated direct pollution coefficients for tourist expenditure based upon fuel use. This has been incorporated into the B^I matrix in the trade accounts.

Pollution is also generated directly in domestic public and private consumption and this is accounted for in the following way:

$$P^{S,C,N} = B^C F_C^D \quad (5)$$

where $P^{S,C,N}$ is a $p \times c$ matrix of total pollutants directly generated in the expenditure on exogenous domestic consumption, where element $p^{S,C,N}_{ij}$ is the total amount of pollutant i directly generated by one unit of final exogenous domestic consumption expenditure j , B^C is a $p \times c$ matrix of direct pollution coefficients, where the element b^C_{ij} is the amount of pollutant i directly generated by one unit of expenditure in final domestic consumption expenditure account j .

Total pollution is attributed through combining equations (4) and (5) to produce:

$$P^{S,N} = P^{S,I,N} + P^{S,C,N} = \left(B^{I,N} (1 - S^N)^{-1} \Phi_c + B^C \right) F_C^D \quad (6)$$

where $P^{S,N}$ is a $p \times c$ matrix where the element $p^{S,N}_{ij}$ is the total amount of pollutant i generated directly and indirectly by expenditure of domestic consumption account type j .

³ This having been said, the informational needs are much less than with the “ecological footprint” approach.

In the exercise performed here we have a single pollutant, CO₂, and there are 6 exogenous domestic consumption accounts, 5 household accounts and the government account. The full SAM is a 43 x 43 matrix. This means that the NCLAS matrix of total direct and indirect pollution attributed to domestic consumption, P^{S,N}, is in this case a 1 x 6 row vector.

5. The Results of the SAM CO₂ Pollution Attribution for Scotland using NCLAS

The following results are based on the Scottish Environmental SAM for 1999 and corresponding pollution coefficients for CO₂. This model attributes the pollution to domestic private and public consumption. The NCLAS system exogenises domestic consumption but endogenises the foreign and capital accounts. This has the effect of broadly attributing the pollution generated within Scotland from the production of export commodities to the production and consumption accounts that use imports. We are interesting in identifying commodities whose consumption involves, directly and indirectly, high CO₂ generation. We are also interested in determining the contribution of different private and public final consumption sectors to total pollution generation. To perform this attribution we use elements of equation (6).

Figure 1. CO₂ Intensity of Production to Meet Local Final Consumption Demand, with Endogenised Trade and Capital Formation, for Scotland 1999

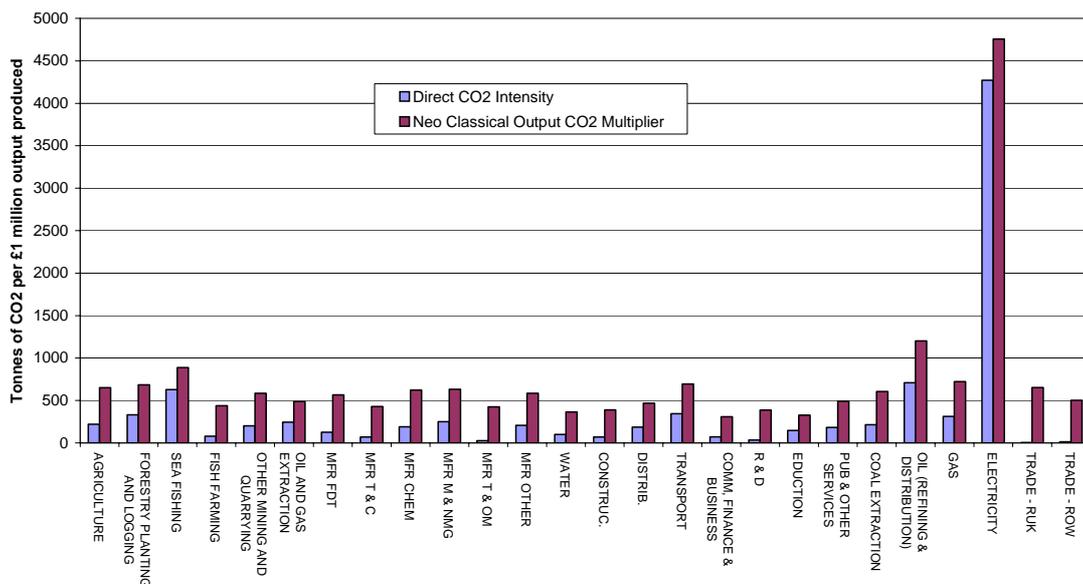


Figure 1 illustrates the direct and direct and indirect CO₂ pollution intensities entailed by the production required to meet £1 million domestic consumption expenditure on each of the 24 production sectors and the two import accounts. The direct pollution intensity corresponds to the appropriate entry in the B^I vector. The direct plus indirect pollution intensities are read off the $B^I[I-S]^{-1}$ vector.

It is clear from Figure 1 that electricity production is by far the most CO₂ intensive commodity that enters the domestic consumption bundle. In the case of electricity, most of the CO₂ is generated directly. However, this is not typical of other sectors. For example, agriculture has a direct CO₂ intensity of 220.56 tons per £1 million but a NCLAS CO₂ multiplier value for 650.55 tons per £1 million. Other sectors that exhibit large differences once indirect effects are incorporated include fish farming, all the manufacturing sectors, commercial, finance and business services and research and development.

One issue raised by Figure 1 is the role of imports. Their direct coefficients are very low, comprising solely of the pollutants generated by tourists. However, their indirect effects are relatively high, especially for the RUK account. The implied CO₂ generated by the RUK exports required to finance RUK imports puts that sector in the top 10 in Scotland in terms of its pollution intensity. From a purely environmental point of view, where the import pollution multiplier value is less than the domestic value for a particular sector, the country or region should import. Where the import pollution is higher, the country should produce domestically. Of course, this perspective seems at odds with the ecological footprint approach, which might categorise such behaviour as exporting pollution.

The results of the NCLAS attribution to final demand for CO₂ are illustrated here in Figure 2. These attribution results are taken from the $P^{S,N}$ vector. They show the total CO₂ emissions generated in Scotland in 1999 that are ultimately attributable to each category of final demand as a share of the total Scottish CO₂ generation. These results include not only the CO₂ generated in production, but also that generated directly in consumption.

Figure 2 Attribution Index for Scotland (1999) to Local Final Consumption Demand in the Neo - Classical Linear Attribution System (with Trade and Capital Formation Determined Endogenously)

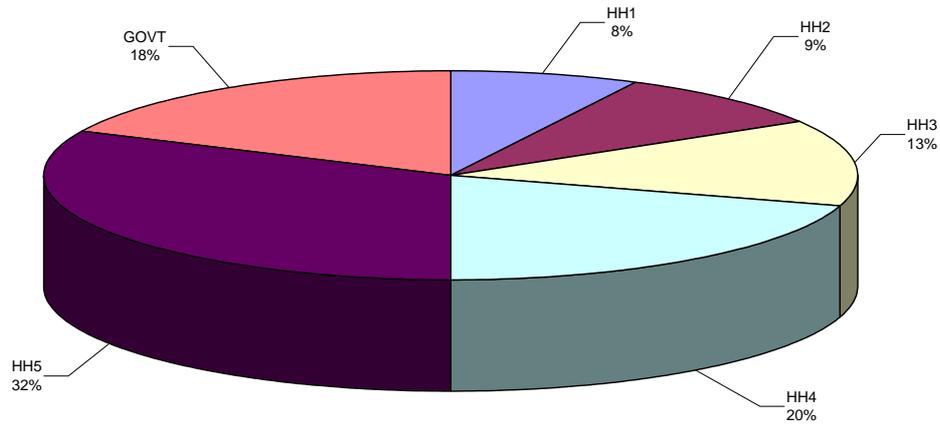


Figure 2 shows clearly that the total CO₂ created by public consumption is much less than that created by private consumption. Public consumption directly or indirectly accounts for only 18% of total CO₂ emissions. Further, the absolute amount of CO₂ attributed to the consumption of household types rises monotonically with income. Whilst the consumption of the lowest income quintile amounts to 8% of all Scottish CO₂, that of the top quintile generates 32% of all Scottish CO₂.

Figure 3. CO₂ Intensities of Scottish Local Final Demand Consumption, with Endogised Trade and Capital Formation.

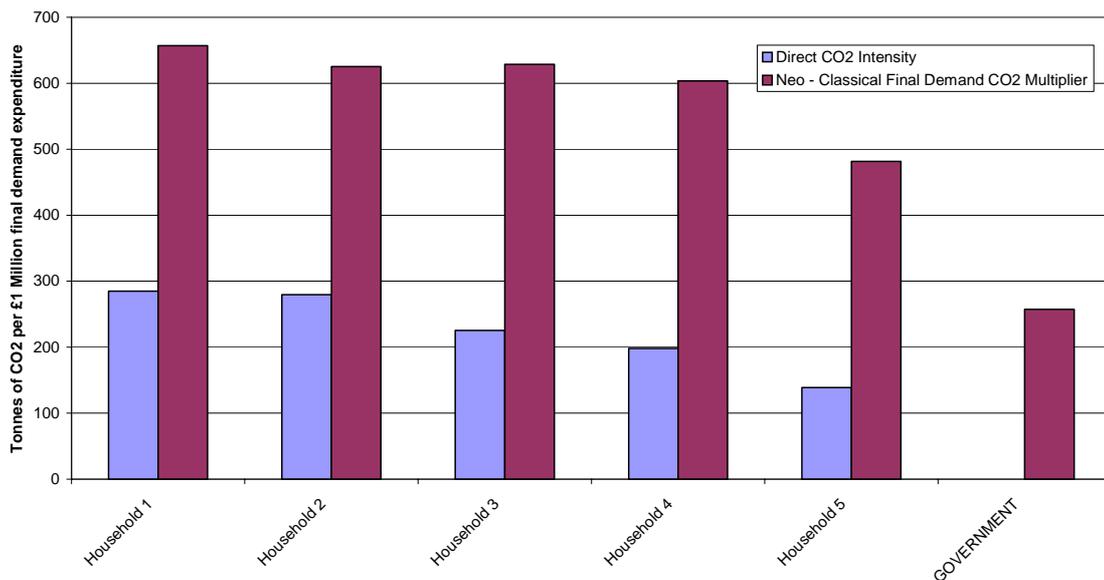


Figure 3 shows the CO₂ emissions for £1 million of domestic expenditure by the different consumption accounts. This corresponds to the appropriate element of the vector $[B^{L,N}(1-S^N)^{-1}\Phi_C + B^C]$. The first point to make is that public consumption has a low CO₂ intensity, much lower than any household group. Second, CO₂ intensity of expenditure falls with household expenditure. For example, £1 million of expenditure for households in the lowest quintile income group has a NCLAS CO₂ multiplier of 657 tons. Households in the highest income quintile have a figure 25% lower than this. This result is consistent with the fact that energy use, particularly for heating and lighting purposes, tends to fall, per unit of expenditure, as income rises. This suggests that a tax on energy use intended to reduce emission generation would tend to be regressive.

6. Conclusions

The attribution exercise outlined in this paper combines a rigorous analytical framework with detailed information on the Scottish economy. It produces results that are both of policy interest and intuitively appealing. Whilst adopting the viewpoint that all pollution should be attributed to domestic consumption, we avoid the enormous data requirements and jurisdictional issues thrown up by the ecological footprint approach. However, a number of extensions and improvements are possible, some of which are already in train.

First, we expect the range of pollutants for which Scottish-specific coefficients are available will increase in the future, and that the accuracy of existing estimates will improve. Second, meeting pollution targets, particularly for CO₂ emissions, is a UK-wide responsibility, but the delivery of policy has been devolved to the nations of the UK and within England delegated to the regions. Therefore a UK inter-regional attribution analysis is of value in order to identify the extent of implicit inter-regional pollution flows. We have made a start on this in a limited IO context (Ferguson *et al*, 2003) and have undertaken trials with an inter-regional SAM.

Finally, whilst an environmental accounting system is important, it is only the first step on the development of an effective environmental policy. From an economic point of view this implies relaxing the rigid assumptions of IO and SAM analysis,

towards a Computable General Equilibrium (CGE) approach. However, an environmental SAM is a key element of the data base required for such a modelling extension.

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APPENDIX 1: INTERMEDIATE DEMAND

Intermediate Demand Sector	IO CLASSIFICATION
Agriculture	1
Forestry planting and logging	2.1, 2.2
Sea fishing	3.1
Fish farming	3.2
Other mining and quarrying	6, 7
Oil and gas extraction	5
Manufacture of food , drink and tobacco	8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18.1, 18.2, 19, 20
Manufacture of textiles and clothing	21, 22, 23, 24, 25, 26, 27, 28, 29, 30
Manufacture of chemicals etc	36, 37, 38, 39, 40, 41, 42, 43, 44, 45
Manufacture of metal and non-metal goods	46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61
Manufacture of transport and other machinery, electrical and instrument engineering	62, 63, 64, 65, 66, 67, 68, 69, 70, 71, 72, 73, 74, 75, 76, 77, 78, 79, 80, 81, 82
Other manufacturing	31, 32, 33, 34, 81, 82, 83, 84
Water	87
Construction	88
Distribution	89, 90, 91, 92
Transport	93, 94, 95, 96, 97
Communications, finance and business	98,99, 100.1, 100.2, 101, 102, 103, 104, 105, 106, 107, 109, 111, 112, 113, 114
R & D	108
Education	116
Public and other services	115, 117, 118, 119, 120, 121
Coal extraction	4
Oil (refining and processing)	35
Gas	86
Electricity	85

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