

SUPPORTING INFORMATION FOR

Distributional Effects of Climate Change Taxation: The case of the UK

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Supplementary Methods

The Input-output Model

Input-output analysis is an analytical framework developed by Professor Wassily Leontief in the late 1930s[1], work for which he received the Nobel Prize in Economic Science in 1973. The fundamental purpose of the input-output framework is to analyse the interdependence of industries in an economy [2]. The mathematical structure of an input-output system consists of n linear equations as shown in Equation 1. The equation depicts that the production of an economy depends on intersectoral relations and final demand.

$$\begin{aligned} x_1 &= x_{11} + x_{12} + \dots + x_{1n} + y_1 \\ x_2 &= x_{21} + x_{22} + \dots + x_{2n} + y_2 \\ &\vdots \\ x_n &= x_{n1} + x_{n2} + \dots + x_{nn} + y_n \end{aligned} \quad (1)$$

The equation 1 can be rewritten as:

$$x_i = \sum_{j=1}^n a_{ij} x_j + y_i \quad (2)$$

Where n is the number of economic sectors of an economy; the x_i represents the total economic output of i th sector; y_i is the final demand of sector i . x_{ij} represents the monetary flows from i th sector to j th sector. Technical coefficient a_{ij} defined by dividing the inter-sectoral flows from i to j (x_{ij}) with total output of j (x_j),

$$a_{ij} = x_{ij} / x_j \quad (3)$$

Therefore, Equation (2) can be rewritten so as to include the technical coefficient (a_{ij}), the developed equation is:

$$x_i = \sum_{j=1}^n a_{ij} x_j + y_i \quad (4)$$

In matrix notation and for the economy as a whole, the Eq (4) can be shown in matrix notation as:

$$X = AX + Y \quad (5)$$

where A is the coefficient matrix.

To solve for x , we get total output flowed to final demand

$$X = (I - A)^{-1}Y \quad (6)$$

Where $(I-A)^{-1}$ is known as the Leontief inverse matrix, which shows the total production of each sector required to satisfy the final demand in the economy [2].

The Environmental Input-output Model

Environmental input-output analysis (IOA)[2-3], now a well-developed and established method in life cycle assessment and energy analysis, determines the economy-wide environmental repercussions stemming from the purchase, y , of an individual product or service,

$$f = F(I - A)^{-1}y \quad (7)$$

where $(I - A)^{-1}$ is known as the Leontief inverse matrix, which shows the total production of each sector required to satisfy a particular final demand in the economy; f is a vector with each element representing the emissions instigated from the purchase of y , F is a matrix with the rows representing the emission intensities of each pollutant in each economic sector, I is the identity matrix, A is a matrix showing the monetary relationship between different sectors in the economy (the technology), and y is a vector of the final demand purchases from each sector¹. We used only the final demand from UK domestic production (excluded imports) as the taxes are only levied on UK domestic industry and products.

¹ For clarity, in this paper, matrices are indicated by capital letters; vectors by small letters; and scalars by lower case letters.

Supplementary Data

MOSAIC Database

Marginal cost curve estimates are taken from the Climate Change Committee [4] to impute emission reductions for different sectors. Data on greenhouse gas emissions of industry sectors are published by the UK Office for National Statistics [5]. Input-output tables for the UK economy are provided by the Stockholm Environment Institute, York [6]. Consumer expenditures per income group are taken from the Family Expenditure Survey [7], and expenditures per lifestyle group are from the MOSAIC database [8]. MOSAIC is a commercial geo-demographic market segmentation system, which classifies all consumers in the UK according to 11 neighborhood groups and 61 neighborhood types (full description in Table S4), which can be interpreted as lifestyles (see [9]).

MOSAIC is a commercial geo-demographic market segmentation system, which classifies all consumers in the UK according to 11 neighborhood groups and 61 neighborhood types (full description in Table S4), which can be interpreted as lifestyles (see (4)). The MOSAIC lifestyle profiles are mainly based on census data which is augmented with a variety of other data sources including expenditure and income information, electoral roll, Experian lifestyle survey information, and consumer credit activities, alongside the post office address file, shareholders register, house prices and council tax information, and ONS local area statistics (see [9]).

The rationale behind using geo-demographic consumption information is that places and people are inextricably linked. Knowledge about the ‘where-about’ of people reveals information about them. Such approaches have proven to work well, because people with similar lifestyles tend to cluster – (see [10]). Geo-demographic lifestyle classifications are built from the bottom-up based on spatially specific variables covering characteristics of both people and places [10]. Hence, the introduction of this type of data does not only allow the extension of the analysis ‘into space’,

but also ultimately the establishment of links between consumption, lifestyles and the physical environment in which activities are taking place.

Supplementary Figures

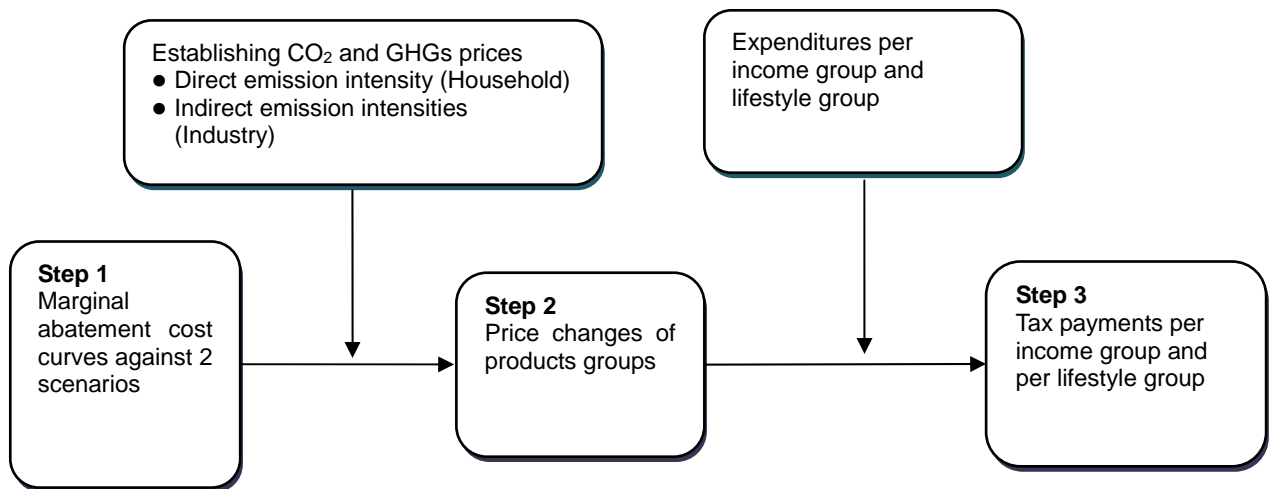
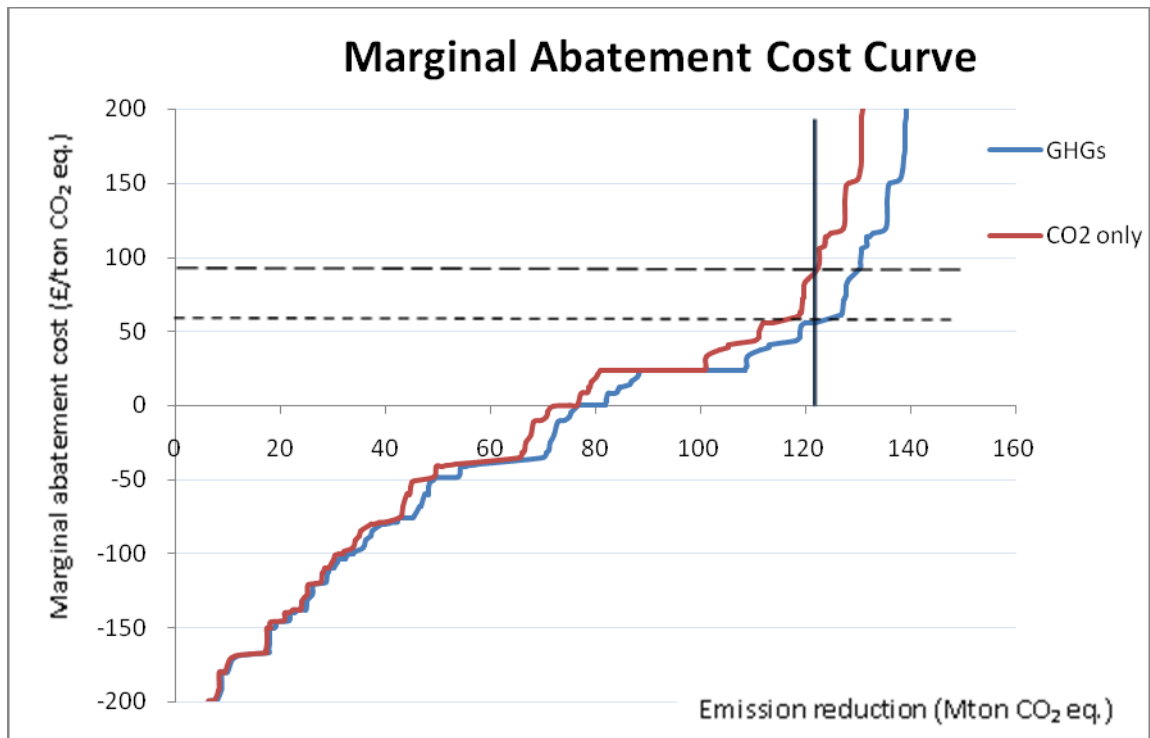


Figure S1: Steps to measure CO₂ and GHGs tax payments



Note: the red line represents the abatement cost of CO₂ emissions and the blue line indicates the abatement cost of GHG emissions. The parts of the curves under the x axis show negative abatement cost or positive net present values (3.5 % discount rate), i.e. over the lifetime of the technology it saves more than it costs.

Figure S2: Tax rates result from intersection of marginal abatement cost curves and the UK emission reduction targets by 2020

Supplementary Tables

Consumption categories		CO ₂ tax	Consumption categories	GHG tax
1	GAS & OTHER FUELS	102.8	GAS & OTHER FUELS	65.3
2	ELECTRICITY	77.3	ELECTRICITY	48.2
3	OPERATION OF PERSONAL TRANSPORT EQUIPMENT	18.5	OPERATION OF PERSONAL TRANSPORT EQUIPMENT	11.3
4	TRANSPORT SERVICES	13.9	MEAT EXCL POULTRY	9.0
5	MEAT EXCL POULTRY	4.4	TRANSPORT SERVICES	8.6
6	POULTRY MEAT	4.2	WATER SUPPLY	7.9
7	WATER SUPPLY	4.0	POULTRY MEAT	6.8
8	VEGETABLE AND ANIMAL OILS	4.0	FRUIT AND VEG	6.5
9	FRUIT AND VEGETABLE	3.7	GRAIN PRODUCTS	5.9
10	GRAIN PRODUCTS	3.7	DAIRY PRODUCTS	4.7

Table S1: Top ten consumption products with the highest price changes after CO₂ and GHG taxation. The GHG tax and CO₂ tax lead to different distributions of the tax burden across consumption categories. The most affected sectors in both categories are ELECTRICITY and GAS & OTHER FUELS with considerable price increases. The high price changes of these two product groups result from their high CO₂ emission intensities. For example, GAS AND OTHER FUELS is the most affected consumption category with a doubling in prices; high levels of CO₂ emissions in this category are caused, for instance, by cooking and heating. The next most affected category is ELECTRICITY where a large amount of CO₂ emissions is created during the production process through burning fossil fuels. The price changes for OPERATION OF PERSONAL TRANSPORT EQUIPMENT and TRANSPORT SERVICES are also large with 18.5 percent and 13.9 percent, respectively, due to combustion of gasoline and associated emissions.

Consumption categories		CO2 tax	GHG tax
1	MEAT AND MEAT PRODUCTS	4.4	9.0
2	POULTRY MEAT AND POULTRY MEAT PRODUCTS	4.2	6.8
3	FISH	3.4	6.8
4	FRUIT AND VEGETABLE	3.7	6.5
5	OILS AND FATS	4.0	5.7
6	DAIRY PRODUCTS	3.7	4.8
7	GRAIN PRODUCTS	3.7	5.9
8	BREAD, RUSKS, BISCUITS ETC	3.4	2.6
9	COCOA	3.0	2.1
10	OTHER FOOD PRODUCTS (INCL. SUGAR)	3.1	2.5
11	NON-ALCOHOLIC BEVERAGES	3.4	2.7
12	ALCOHOLIC BEVERAGES	2.2	1.6
13	TOBACCO	2.2	1.7
14	CLOTHING	2.1	1.5
15	FOOTWEAR	2.0	1.5
16	ACTUAL RENTALS FOR HOUSING	0.5	0.3
17	IMPUTED RENTALS FOR HOUSING	0.5	0.3
18	MAINTENANCE AND REPAIR OF THE DWELLING	3.6	2.3
19	WATER SUPPLY	4.0	7.9
20	ELECTRICITY	77.3	48.2
21	GAS & OTHER FUELS	102.8	65.3
22	FURNITURE, FURNISHINGS, CARPETS ETC.	2.9	2.0
23	HOUSEHOLD TEXTILES	3.1	2.1
24	HOUSEHOLD APPLIANCES	2.5	1.7
25	GLASSWARE, TABLEWARE & HOUSEHOLD UTENSILS	3.4	2.3
26	TOOLS AND EQUIPMENT FOR HOUSE & GARDEN	3.2	2.2
27	GOODS & SERVICES FOR HOUSEHOLD MAINTENANCE	1.4	0.9
28	MEDICAL PRODUCTS, APPLIANCES & EQUIPMENT	2.2	1.5
29	OUT-PATIENT SERVICES	1.6	1.1
30	HOSPITAL SERVICES	1.5	1.0
31	PURCHASE OF VEHICLES	3.2	2.0
32	OPERATION OF PERSONAL TRANSPORT EQUIPMENT	18.5	11.3
33	TRANSPORT SERVICES	13.9	8.6
34	POSTAL SERVICES	2.6	1.7
35	TELEPHONE & TELE FAX EQUIPMENT	2.1	1.5
36	TELEPHONE & TELE FAX SERVICES	1.5	1.0
37	AUDIO-VISUAL, PHOTO & INFO. PROCESSING EQUIPMENT	2.3	1.6
38	OTHER MAJOR DURABLES FOR RECREATION & CULTURE	3.0	2.4
39	OTHER RECREATIONAL EQUIPMENT ETC.	2.8	3.8
40	RECREATIONAL & CULTURAL SERVICES	1.4	1.0
41	NEWSPAPERS, BOOKS & STATIONERY	2.8	1.9
42	EDUCATION	1.6	1.1

43	CATERING SERVICES	2.4	1.9
44	ACCOMMODATION SERVICES	2.4	1.9
45	PERSONAL CARE	2.5	1.7
46	PERSONAL EFFECTS NEC	2.6	1.8
47	SOCIAL PROTECTION	1.6	1.1
48	INSURANCE	2.0	1.3
49	FINANCIAL SERVICES NEC	1.0	0.6
50	OTHER SERVICES NEC	1.6	1.2

Table S2: Price changes of consumption categories after CO₂ and GHG taxation

FOOD AND DRINKS	MEAT AND MEAT PRODUCTS POULTRY MEAT AND POULTRY MEAT PRODUCTS FISH FRUIT AND VEGETABLE OILS AND FATS DAIRY PRODUCTS BREAD, RUSKS, BISCUITS ETC COCOA OTHER FOOD PRODUCTS (INCL. SUGAR) NON-ALCOHOLIC BEVERAGES ALCOHOLIC BEVERAGES TOBACCO
CLOTHING AND FOOTWEAR	CLOTHING FOOTWEAR
HOUSING	ACTUAL RENTALS FOR HOUSING IMPUTED RENTALS FOR HOUSING MAINTENANCE AND REPAIR OF THE DWELLING WATER SUPPLY ELECTRICITY GAS & OTHER FUELS FURNITURE, FURNISHINGS, CARPETS ETC. HOUSEHOLD TEXTILES HOUSEHOLD APPLIANCES GLASSWARE, TABLEWARE & HOUSEHOLD UTENSILS TOOLS AND EQUIPMENT FOR HOUSE & GARDEN GOODS & SERVICES FOR HOUSEHOLD MAINTENANCE
HEALTH	MEDICAL PRODUCTS, APPLIANCES & EQUIPMENT OUT-PATIENT SERVICES HOSPITAL SERVICES
TRANSPORT	PURCHASE OF VEHICLES OPERATION OF PERSONAL TRANSPORT EQUIPMENT

	TRANSPORT SERVICES
COMMUNICATION	POSTAL SERVICES TELEPHONE & TELE FAX EQUIPMENT TELEPHONE & TELE FAX SERVICES
RECREATION&CULTURE	RECREATIONAL & CULTURAL SERVICES NEWSPAPERS, BOOKS & STATIONERY
EDUCATION	EDUCATION
RESTAURANTS&HOTELS	CATERING SERVICES ACCOMMODATION SERVICES
MISC GOODS&SERVICES	PERSONAL CARE PERSONAL EFFECTS NEC SOCIAL PROTECTION INSURANCE FINANCIAL SERVICES NEC OTHER SERVICES NEC

Table S3: Ten aggregate consumption categories

Group	Group Description	% Household	Type	Type Description	% Household
A	<p>Symbols of Success:</p> <p><i>Symbols of Success</i> contains people whose lives are 'successful' by whatever yardsticks society commonly uses to measure success. These are people who have rewarding careers rather than jobs, who live in sought after locations, who drive the more modern and expensive cars and who indulge in the most exotic leisure pursuits. Most, though not all, appear to enjoy stable household arrangements.</p>	9.62	A01	Global Connections	0.72
			A02	Cultural leadership	0.92
			A03	Corporate Chieftains	1.12
			A04	Golden Empty Nesters	1.33
			A05	Provincial Privilege	1.66
			A06	High Technologists	1.82
			A07	Semi-Rural Seclusion	2.04
B	<p>Happy Families:</p> <p><i>Happy Families</i> contains people whose focus is on career, home and family. These are mostly younger age groups who are married, or at least in a permanent relationship, and are now raising children in post war family houses, often in</p>	10.76	B08	Just Moving in	0.91
			B09	Fledgling Nurseries	1.18
			B10	Upscale New Owners	1.35
			B11	Families Making Good	2.32
			B12	Middle Rung Families	2.86
			B13	Burdened Optimists	1.96

	areas of the country with rapidly growing populations. The focus of expenditure is on equipment for the home and garden, and the immediate family unit is the principal focus of leisure activities.		B14	In Military Quarters	0.17
C	<p>Suburban Comfort:</p> <p><i>Suburban Comfort</i> comprises people who have successfully established themselves and their families in comfortable homes in mature suburbs. Children are becoming more independent, work is becoming less of a challenge and interest payments on homes and other loans are becoming less burdensome. With more time and money on their hands, people can relax and focus on activities that they find intrinsically rewarding.</p>	15.10	C15 C16 C17 C18 C19 C20	Close to Retirement Conservative Values Small Time Business Sprawling Subtopia Original Suburbs Asian Enterprise	2.81 2.84 2.93 3.08 2.41 1.02
D	<p>Ties of Community:</p> <p><i>Ties of Community</i> is comprised of people whose lives are mostly played out within the confines of close knit communities. Living mostly in older houses in inner city neighbourhoods or in small industrial towns, most of these people own their homes, drive their own cars and hold down responsible jobs. Community norms rather than individual material ambitions shape the pattern of most residents' consumption.</p>	16.04	D21 D22 D23 D24 D25 D26 D27	Respectable Rows Affluent Blue Collar Industrial Grit Coronation Street Town Centre Refuge South Asian Industry Settled Minorities	2.65 3.12 3.82 2.81 1.13 0.88 1.62
E	<p>Urban Intelligence:</p> <p><i>Urban Intelligence</i> mostly contains young and well educated people who are open to new ideas and influences. Young and single, and few encumbered with children, these people tend to be avid explorers of new ideas and</p>	7.19	E28 E29 E30 E31 E32 E33	Counter Cultural Mix City Adventurers New Urban Colonists Caring Professionals Dinky Developments Town Gown Transition	1.36 1.27 1.36 1.08 1.10 0.76

	fashions, cosmopolitan in their tastes and liberal in their social attitudes. Whilst eager consumers of the media and with a sophisticated understanding of brand values, they like to be treated as individuals, and value authenticity over veneer.		E34	University Challenge	0.26
F	<p>Welfare Borderline:</p> <p><i>Welfare Borderline</i> is comprised of many people who are struggling to achieve the material and personal rewards that are assumed to be open to all in an affluent society. Few hold down rewarding or well paying jobs and, as a result, most rely on the council for their accommodation, on public transport to get around and on state benefits to fund even the bare essentials. The lack of stability in many family formations undermines social networks and leads to high levels of anti social behaviour among local children.</p>	6.43	F35 F36 F37 F38 F39 F40	Bedsit Beneficiaries Metro Multiculture Upper Floor Families Tower Block Living Dignified Dependency Sharing a Staircase	0.71 1.67 1.72 0.49 1.34 0.50
G	<p>Municipal Dependency:</p> <p><i>Municipal Dependency</i> mostly contains families on lower incomes who live on large municipal council estates where few of the tenants have exercised their right to buy. Often isolated in the outer suburbs of large provincial cities, Municipal Dependency is characterised as much by low aspirations as by low incomes. Here people watch a lot of television and buy trusted mainstream brands from shops that focus on price rather than range or service.</p>	6.71	G41 G42 G43	Families on Benefits Low Horizons Ex-industrial Legacy	1.21 2.64 2.86
H	<p>Blue Collar Enterprise:</p> <p><i>Blue Collar Enterprise</i> comprises people who, though not</p>	11.01	H44 H45	Rustbelt Resilience Older Right to Buy	3.00 2.67

	necessarily very well educated, are practical and enterprising in their orientation. Many of these people live in what were once council estates but where tenants have exercised their right to buy. They own their cars, provide a reliable source of labour to local employers and are streetwise consumers. Tastes are mass market rather than individualistic and focus on providing comfort and value to family members.		H46 G47	White Van Culture New Town Materialism	3.17 2.17
I	Twilight Subsistence: <i>Twilight Subsistence</i> consists of elderly people who are mostly reliant on state benefits, and live in housing designed by local authorities and housing associations. Some live in old people's homes or sheltered accommodation, while others live in small bungalows, set in small enclaves within larger council estates. Most of these people spend money only on the basic necessities of life.	3.88	I48 I49 I50	Old People in Flats Low Income Elderly Cared for Pensioners	0.83 1.63 1.43
J	Grey Perspectives: <i>Grey Perspectives</i> consists mostly of pensioners who own their homes and who have some source of income beyond the basic state pension. Many of these people have, on retirement, moved to the seaside or the countryside to live among people similar to themselves. Today many of these people have quite active lifestyles and are considered in their purchasing decisions.	7.88	J51 J52 J53 J54 J55 J56	Sepia Memories Childfree Serenity High Spending Elders Bungalow Retirement Small Town Seniors Tourist Attendants	0.75 1.34 1.53 1.26 2.71 0.30
K	Rural Isolation: <i>Rural Isolation</i> contains people whose pattern of living is distinctively rural. They live not just outside major population centres but also deep in the	5.39	K57 K58 K59 K60	Summer Playgrounds Greenbelt Guardians Parochial Villagers Pastoral Symphony	0.29 1.74 1.64 1.31

	countryside, in small communities which have been little influenced by the influx of urban commuters. These are places where people with different levels of income share attachments to local communities, and where engagement with the community and with the natural environment are more important to most residents than material consumption.		K61	Upland Hill Farmers	0.41
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Table S4: Description of MOSAIC groups [9]

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