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Carbon Taxes, Consumer Demand and Carbon Dioxide Emissions: A Simulation Analysis for the UK

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I. INTRODUCTION

In this paper we examine the effects of a carbon tax, one of the possible instruments for reducing carbon dioxide (CO_2) emissions. Such taxes are currently being proposed as a means of reducing CO_2 emissions, motivated by concerns about the global greenhouse effect and its potential impact on global climate and sea levels (Cline, 1991) and on global economies (Nordhaus, 1991). We therefore take as our problem the reduction of CO_2 emissions by the UK economy by use of a carbon tax, and the corresponding effect of this tax on the purchasing power and economic behaviour of households.

If they were introduced, carbon taxes would affect the price of fossil fuels in the UK, and thus UK consumer prices, both directly for fuels and indirectly for manufactured goods. These price changes would in turn affect the level and structure of UK final demand, and it is this post-tax UK final demand which will determine UK fossil fuel use, and thus CO_2 emissions. In particular, we investigate the social effects of a carbon tax, by considering the distribution of the increased tax burden across consumers.

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Our analysis is in four stages. First, we use an input–output framework to assess the likely impact of carbon taxes on fossil fuels upon the prices of consumer goods. Second, these price changes are used as inputs to the IFS Simulation Program for Indirect Taxation (SPIT), to estimate the effects on consumer demand. Third, the structure of estimated consumer demand allows estimates of fossil fuel use, and thus CO_2 emissions, to be calculated. Finally, the distributional implications of this tax incidence are analysed.

Various levels of carbon tax are used in the simulations, and the impacts of this tax on government revenue and consumer welfare are also assessed. Particular attention is paid to the achievement of a 20 per cent reduction in CO_2 emissions attributable to consumer demand, in line with the 'Toronto target'. This target is combined with a range of other tax and benefit reforms, aimed at reducing the inequities in distribution brought about by a simple carbon tax.

II. THE GLOBAL GREENHOUSE EFFECT AND THE CARBON TAX

Recent research into the Earth's climate suggests that the release of 'greenhouse gases', particularly CO_2, into the atmosphere is likely to cause major and potentially irreversible changes in global climate by the year 2050 (e.g. Bolin, Doos, Jager and Warrick, 1986). It seems that although a substantial increase in the concentration of atmospheric CO_2 is unavoidable over the next few decades, there may exist possibilities for limiting this increase by the adoption of suitable economic and technological policies on a global scale (e.g. Svennigsson, 1985).

If the rate of CO_2 emissions is to be reduced, the level and mix of fossil fuel use will need to be altered substantially to reduce the carbon intensity of fuel production and use. One approach is to levy a carbon tax on fossil fuels, with the tax proportionate to the carbon content of the fuel. For example, a tonne of hard coal contains about 1.4 times as much carbon as a tonne of oil, so the tax on coal should be 1.4 times as high per tonne as that on oil. Pearce (1991) has surveyed the recent literature on the likely effects of carbon taxes. Further important recent contributions are by Barker and Lewney (1991), on the macroeconomic modelling of environmental policies, and Sondheimer (1991), specifically on the macroeconomic effects of carbon taxes. A comprehensive survey of the long-run macroeconomic consequences of greenhouse gas abatement is given by Boero, Clarke and Winters (1991).

In this paper we concentrate on the effects of a carbon tax on income distribution and government revenue. Recent literature in this area includes Johnson, McKay and Smith (1990), who consider the additional tax burden generated by a selection of possible taxes on consumer spending and its distribution across households. Poterba (1991) has estimated the distributional effects of a carbon tax for the US, using both current and life-cycle concepts of income. Scott (1992) has estimated the distributional impact of a carbon tax in

Ireland. Smith (1992) has made estimates of the distributional impact of the proposed carbon tax in six EU Member States.

None of the above studies is 'behavioural', in the sense that none attempts to account for consumers' response to the altered absolute and relative prices of commodities brought about by a carbon tax. Also, none of these studies takes account of the effects of a carbon tax on the prices of *non-fuel* household purchases, even though about half of all fuel use and CO_2 emissions are associated with the production of goods by industrial activity.

A study that does use an input–output approach, thus taking account of the effects of a fuel tax on non-fuel purchases, is that by Casler and Rafiqui (1993). However, their analysis does not allow for the effect of behavioural responses to the tax incidence on consumer behaviour.

Pearson and Smith (1991) have made a study of the effects of a carbon tax on household behaviour (i.e. a behavioural study), but only taking account of the increased price of domestic fuels, not other purchases.

In contrast to the above literature, the present study offers a behavioural analysis of the effects of a carbon tax, which also takes account of the effects of such a tax on the prices of non-fuel goods purchased by households. As far as we are aware, this is the first study that seeks to examine the effects of carbon taxes on household behaviour in such a comprehensive way.

III. THE INPUT–OUTPUT FRAMEWORK FOR MODELLING THE EFFECTS OF CARBON TAXES

To examine the scope for implementing such a carbon tax in the UK, one needs a modelling framework for how fossil fuels are used in an economy. Such an approach would need to distinguish between the 'direct consumption demand' for fossil fuels and the 'indirect consumption demand'. For example, households purchase fuels for direct use (e.g. petrol, heating oil, coal, gas); this constitutes direct consumption demand. They also purchase goods the production of which has entailed the use of fossil fuels (e.g. a motor car has entailed large amounts of fossil fuel use in its manufacture); this constitutes indirect consumption demand.

The indirect consumption demand for fossil fuels can be identified with the derived demand for these fuels through production; thus we may identify the indirect consumption demand with the 'production demand' for fossil fuels.

This production demand can be further subdivided into 'direct production demand' and 'indirect production demand'. For example, the manufacture of a motor car requires fossil fuel use directly, mainly for space heating and process heating within car manufacturing establishments. This is the direct production demand. However, much fossil fuel is expended in the manufacture of the steel, glass, plastics, electricity etc. used as inputs to the car-making process. This is the indirect production demand.

Our analysis therefore seeks to identify the demand for fossil fuels by producing sector and by fuel, and decomposed into the direct consumption demand, the direct production demand and the indirect production demand. This effectively imputes all fossil fuel use to final demand. Thus the 'carbon requirement' per unit output of each sector could be calculated, and similarly so could the CO_2 emissions. The most appropriate tool for such a sectoral analysis and decomposition is input–output analysis. The details of the calculation of the direct consumption demand and production demand for fossil fuels are given in Gay and Proops (1993) and Proops, Faber and Wagenhals (1993, Chs 6–8).

IV. CARBON TAXES AND CONSUMER DEMAND

The increased production costs caused by a carbon tax will be passed on, to a greater or lesser extent, to the consumer in terms of price increases, the size of which will depend on how much of each fossil fuel is attributable to the manufacture of each type of good. We make the usual input–output assumption that, in the short and even medium run, there is no substitution of fuels in production. This assumption of zero elasticities of substitution between the various fuels, and between fuels and other inputs, means that the price rises calculated will be considerably greater than those where such substitution is allowed in the longer run. The estimates we produce for the price effects of carbon taxes will therefore be akin to upper bounds on the effects that will be observed.

The total CO_2 emissions by an economy can be attributed to total final demand for goods and services (i.e. to disaggregated national product). This methodology is described in Gay and Proops (1993). This final demand can be further disaggregated into demands by consumers, by government, for exports and for the accumulation of stocks and capital goods. This study concentrates on the effects of consumer demand on CO_2 emissions by the UK. (The effect of UK consumer demand on CO_2 emissions overseas is not assessed in this study. For a discussion of this problem, see Proops, Faber and Wagenhals (1993, Ch. 8).)

In the UK, consumer demand accounts for approximately 50 per cent of national product (at factor cost) and approximately 55 per cent of CO_2 emissions (directly and indirectly). Therefore, in this study we shall be examining the possibility of using a carbon tax to achieve a 20 per cent reduction in CO_2 emissions for roughly half of national product and a little over half of total UK CO_2 emissions.

V. THE CARBON TAX RATES COMPARED WITH THOSE IN OTHER STUDIES

As discussed above, in this study we concentrate on the effects of carbon taxes on consumer behaviour. Our methodology is therefore rather confining, in that it allows substitution between goods by consumers, but not between fuels or techniques by producers. As a result, while one would expect to see a long-run effect of a carbon tax on manufacturing (Proops, Faber and Wagenhals, 1993, Ch. 11), with consequent long-run reductions in CO_2 emissions, we take no account of this considerable abatement possibility in our essentially static study. As a result, to achieve a reduction of approximately 20 per cent in direct and indirect CO_2 emissions by households (ignoring the other elements of final demand), the lowest carbon tax we find necessary (Reform 1) is £240.5 per tonne (i.e. $411 per tonne). When revenue neutrality and equity considerations are taken into account (Reform 5), the necessary carbon tax is very high indeed (£444 per tonne; i.e. $755 per tonne).

It is useful to compare the carbon tax rates we use with those in the literature, where long-run substitution in production is allowed for. In his review, Pearce (1991) noted a range of estimates for a carbon tax producing a (generally long-run) reduction of CO_2 emissions of about 20 per cent for the UK. In increasing order of tax level, these include: $34–59 per tonne (Barrett, 1990); $87–205 per tonne (Ingham and Ulph, 1989); and $145–516 per tonne (Barker and Lewney, 1991).

Estimates for approximately 20 per cent CO_2 reduction by other countries included the following: $82 per tonne — US (Chandler and Nicholls, 1990); $100 per tonne — US (Nordhaus and Yohe, 1983); $113 per tonne — US (Congressional Budget Office, 1991); $126 per tonne — Norway (Bye, Bye and Lorentsen, 1989); $300 per tonne — US (Manne and Richels, 1989).

We note that our lowest required carbon tax rate is less than the higher estimate of Barker and Lewney (1991), although our highest required tax exceeds all the quoted estimates. We therefore offer our analysis not as a means of estimating the appropriate level of carbon tax, for the reasons discussed above, but as an illustration of the revenue and distributional implications of carbon taxation, when consumer responses to the resulting price rises are taken into account.

VI. THE SIMULATION METHODOLOGY

This section outlines the micro-simulation routine that investigates the impact of carbon taxes on aggregate government revenue, on CO_2 emissions and its sources, and on household expenditure, and the distribution of these effects across the economy. The simulation routine uses a demand system that is estimated from pooled Family Expenditure Surveys (FESs) for the years 1970–86, a sample of 116,000 households.

A carbon tax will increase the price of most goods and may involve large changes in relative prices. This will cause substantial changes in consumer expenditure that cannot adequately be forecast by simple models that use constant price elasticities. The model used here predicts the response of each household within the 1986 survey — a sample of 7,045 households — to the imposition of a carbon tax. The taxes and prices relating to August 1990 are taken as the base system, household income being reflated to this period. The demand system underlying the simulation routine is an extension of the Almost Ideal Demand System model of Deaton and Muellbauer (1980) and allows expenditure on specific commodity groups to depend on both the price of that group and the relative price of other groups, together with household characteristics.

The simulation program used here incorporates models for different types of household according to the classifications smokers/non-smokers and car-owners/non-car-owners. It covers nine commodity groups (food, alcohol, household energy, clothing, transport, services, petrol, tobacco and other goods) which form 80 per cent of total consumer household expenditure. The two other components of household expenditure — durables and housing — are treated as commodities that are ‘fixed’ or ‘rationed’ by quantity. If the price of any component of the rationed goods changes, then expenditure on them will change by the same proportion. Hence it is assumed that households will maintain the real value of the rationed goods purchased. Expenditure on the rationed goods is evaluated under the new prices, the remaining income being distributed between the remaining nine groups according to the demand system predictions.

The predictions are used to compute government revenue and CO_2 emissions on the assumption that taxes are entirely incident on consumer prices. The SPIT model is described in detail in Baker, McKay and Symons (1990). It has already been used by Johnson, McKay and Smith (1990) and Pearson and Smith (1991) to investigate the distributive consequences of increased indirect taxes on domestic energy, petrol and food. However, as noted above, their analysis did not take account of the major indirect effect of a carbon tax on the prices of all goods, through the increased direct and indirect manufacturing costs resulting from a carbon tax on all fossil fuels.

The FES contains information on expenditure for a fine breakdown of goods, and total expenditure is aggregated into approximately 39 categories of goods that are encompassed by the 11 broad groups. Using UK input–output tables (Central Statistical Office, 1987) and data on UK inland energy consumption (Department of Energy, 1989), CO_2 intensities were calculated for the 39 FES goods categories.

The units used for these intensities are kg CO_2/£ (at 1990 market prices). This use of kg CO_2/£ rather than kg carbon/£ makes obvious the relationship between changes in consumer demand resulting from any tax and the altered CO_2 emissions. However, the literature on carbon taxes generally considers the tax to be upon the carbon content of the fuels, rather than the resulting CO_2 emissions. For consistency with this literature, we specify our carbon taxes in £/tonne of

TABLE 1

CO_2 Intensities of Commodity Groups

Kilograms of CO_2 per pound

Group	*Category*	*(1) Consumption*	*(2) Direct production*	*(3) Indirect production*	*(4) Total*
Food	Other food	0	0.088	0.353	0.441
	Ice-cream, sweets etc.	0	0.088	0.353	0.441
	Hot take-aways etc.	0	0.057	0.416	0.473
Household energy	Fuel, light and power	5.570	5.605	0.979	12.154
Alcohol	Beer etc.	0	0.049	0.104	0.152
	Wine	0	0.049	0.104	0.152
	Spirits	0	0.049	0.104	0.152
Other	Spectacles	0	0.053	0.424	0.477
	Medicines	0	0.023	0.142	0.165
	Books, newspapers etc.	0	0.024	0.162	0.186
	Jewellery, photo etc.	0	0.173	0.486	0.659
	All other	0	0.050	0.240	0.290
Tobacco	All tobacco products	0	0	0.032	0.032
Petrol	Petrol and diesel	5.047	0.225	0.058	5.330
Clothing	Adult clothing etc.	0	0.016	0.068	0.084
	Children's clothing	0	0.018	0.078	0.096
Services	Entertainment	0	0.050	0.375	0.425
	Post, licences etc.	0	0.018	0.239	0.257
	NHS and medical fees	0	0.027	0.164	0.191
	Personal services	0	0.247	2.240	2.487
	Charitable gifts	0	0	0	0
	Holidays	0	0.186	0.217	0.403
	Education fees	0	0.015	0.135	0.150
Transport	New cars etc.	0	0.109	0.445	0.554
	Second-hand cars etc.	0	0	0	0
	Repairs etc.	0	0.223	1.886	2.109
	AA subscriptions etc.	0	0.041	0.289	0.330
	Motor oil	5.570	5.605	0.979	12.154
	VED and car insurance	0	0.062	0.437	0.499
	Taxis and car hire	0	0.717	0.282	0.999
	All public transport	0	1.116	0.153	1.269
Durables	Furniture, floors etc.	0	0.063	0.155	0.218
	Electrical	0	0.019	0.156	0.175
	Kitchen	0	0.007	0.096	0.103
	Insurance on contents	0	0.062	0.438	0.500
	China, glassware etc.	0	0.584	0.721	1.305
Housing	House — imputed rent	0	0.090	0.359	0.449
	Repairs and decorations	0	0.045	0.179	0.224
	Insurance on dwelling	0	0.062	0.438	0.500

carbon.

The CO_2 intensity for each group of goods is given in Table 1. All figures relate to the amount of CO_2 produced for each pound of expenditure, at 1990 expenditure levels. Column 1 gives the CO_2 intensity relating to consumption of the fossil fuel; column 2 relates to the CO_2 produced directly in production; column 3 relates to indirect production. The final column is the sum of the component parts.

For car fuel the CO_2 intensity is determined largely by consumption. The goods that have a significant production element are energy and public transport (with emissions directly in their production) and transport repair, personal services and china (with contribution indirectly through their production). Note that household energy consumption is treated as a single good, so there is no substitutability in consumption between gas, electricity, coal and other fuel sources. The inclusion of separate energy categories in the demand system caused problems of robustness in estimation. This is an area for future work.

From the table we see that each pound of consumer expenditure on public transport generates 1.27kg of CO_2. Under our assumptions, the impact of a carbon tax on public transport would reflect the pollutant value of both the direct use of public transport by consumers and the indirect effect caused in the consumption, and thus production, of other goods; in other words, it will be proportional to the CO_2 intensity of the good.

Thus

$$t_{ik} = \alpha\, c_{ik}$$

where t_{ik} is the incidence of the carbon tax on the kth good within the ith commodity group, α is the equivalent tax on CO_2 emissions (£/kg) and c_{ik} is the CO_2 intensity for good ik.

The price indices for the broad commodity groups are taken from the published monthly retail price index series. The imposition of carbon taxes, or any change to the overall effective indirect tax rates on individual goods, is translated into price changes for the broad commodity groups, as the weighted sum of the percentage price changes of goods within each group; thus for the ith group,

$$\frac{\Delta P_i}{P_i^0} = \sum_k w_{ik}(\log p_{ik}^1 - \log p_{ik}^0) \qquad (i=1,\ldots,13)$$

where P_i is the price index for the ith commodity group, p_{ik} is the price index of good ik and w_{ik} is the proportion of expenditure on the ith group spent on good ik. The superscripts 0 and 1 indicate pre- and post-tax change respectively. We assume constant weights, w_{ik}, for the components of commodity group price changes. This corresponds to the method of construction of the retail price indices used in estimation.

The simulation program adopts a relatively simple procedure for 'grossing up' expenditure levels to the national level. The shortfall is corrected by multiplying FES expenditure data by the ratio of National Accounts consumer expenditure to FES expenditure for each commodity group. This yields 'corrected' tax revenue and levels of CO_2 emissions.

VII. THE IMPACT OF CARBON TAXES

This section considers some implications of introducing a carbon tax. As we assume that such a tax would ultimately be entirely incident on final consumers, we can model a carbon tax as a set of indirect taxes on consumer goods, the effective indirect tax depending on the level of the underlying carbon tax on fuels and the CO_2 intensity of the goods consumed. Therefore, we first examine possible carbon- tax-induced effective indirect tax systems that will reduce CO_2 emissions from the consumption sector by approximately 20 per cent, the target suggested at the 1988 Toronto conference.

Such reforms substantially increase government revenue, so we subsequently consider ways this revenue can be used to maintain revenue neutrality by altering other aspects of the tax system, either direct or indirect. We then consider a tax system that reduces CO_2 emissions by almost 20 per cent but does not increase government revenue. We compare the alternative potential policies with respect to their effect on different types of household. When considering government revenue neutrality, we are particularly concerned with the use of policies that have direct effects on real income distribution.

Carbon Taxes, and Tax and Benefit Reforms Considered

In more detail, the reforms we consider are shown in Table 2.

Reform 1 is a simple carbon tax, with no other tax or benefit alterations. The carbon tax is set at a level that reduces CO_2 emissions attributable to household consumption of goods, including fuels, by approximately 20 per cent.

Reform 2 aims to achieve approximately the same reduction in CO_2 emissions as Reform 1, without any increase in the price of petrol. The carbon tax is higher than in Reform 1, and the petrol excise duty is more than halved from its present level.

Reform 3 maintains the carbon tax of Reform 2, but to seek to maintain neutrality of government revenue, VAT is removed. There is a smaller reduction of CO_2 emissions than in Reforms 1 and 2.

All of the above reforms have severely regressive effects on income distribution. Therefore, in Reform 4 the neutrality of government income is approximately maintained by adjustments to various benefit payments, rather than VAT abolition. This gives rise to a reduction of CO_2 emissions of little more than half the Toronto target.

TABLE 2

Carbon Taxes, Indirect Tax Reforms and Benefit Reforms Used

	TAX REFORM			BENEFITS REFORM			EFFECT
	VAT (%)	*Petrol excise (£/gal.)*	*Carbon tax (£/tonne)*	*Minimum expenditure (£)*	*Pension (£)*	*Children (£)*	*CO_2 reduction (%)*
Reform 1	15	0.93	240.5	0	0	0	19.7
Reform 2	15	0.45	277.5	0	0	0	19.6
Reform 3	0	0.45	277.5	0	0	0	14.1
Reform 4	15	0.45	277.5	55	7	7	11.3
Reform 5	5	0.60	444.0	45	15	15	17.8

Key: Reform 1. Carbon tax achieving Toronto target.
Reform 2. Carbon tax, plus reduction in petrol excise duty, achieving Toronto target.
Reform 3. Carbon tax, plus reduction in petrol excise duty, plus zero VAT.
Reform 4. Carbon tax, plus reduction in petrol excise duty, plus benefits reform.
Reform 5. Carbon tax, plus reduction in petrol excise duty, plus benefits reform, approximately achieving Toronto target.

Reform 5 seeks to combine the revenue neutrality of Reforms 3 and 4 with the Toronto target reductions in CO_2 emissions from Reforms 1 and 2, as well as seeking to counter the regressive effects of the carbon tax, through benefits adjustment. The CO_2 emissions reduction is still slightly below the Toronto target.

VIII. THE EFFECTS OF THE REFORMS

Using the SPIT model, with Reform 1 we estimate that the carbon tax required to reduce UK CO_2 emissions attributable to consumers by approximately 20 per cent is £240.5 per tonne of carbon. For Reform 2, the necessary tax rate is £277.5 per tonne of carbon. As mentioned above, both of these figures are high compared with most estimates found in the literature for carbon taxes that would achieve the Toronto target. Again we stress that this is because of the assumption of no substitution in production.

Table 3 shows the percentage price change for goods with high CO_2 intensity. Each reform involves a large change in relative prices. Household fuel and petrol prices rise much more than prices for other goods in Reform 1, because of their very high CO_2 intensity. Amongst the remaining groups, the prices of china etc., food and transport show relatively high increases.

TABLE 3

Price Changes for Reforms 1 and 2

Per cent

	Reform 1	*Reform 2*
Household energy	79.0	91.2
Petrol	34.7	–0.5
Durables: china	8.5	9.8
Transport	5.2	6.1
Food	2.9	3.4

Key: Reform 1. Carbon tax achieving Toronto target.
Reform 2. Carbon tax, plus reduction in petrol excise duty, achieving Toronto target.

TABLE 4

Average Weekly Expenditure for Reforms 1 and 2

Pounds per week

	Base	*Reform 1*	*Reform 2*
Food	41.08	39.71	39.99
Beer	6.11	8.19	8.07
Wine	2.08	2.83	2.99
Spirits	1.78	1.86	1.86
Household energy	11.80	15.58	16.47
Clothing	16.58	15.77	16.35
Transport	26.70	24.44	24.51
Services	29.17	26.63	26.49
Petrol	8.29	8.42	6.60
Tobacco	5.11	5.11	5.00
Other goods	16.91	15.70	15.69
Durables	15.45	15.67	15.71
Housing	42.93	44.09	44.27
Total	223.97	223.97	223.97

Key: Reform 1. Carbon tax achieving Toronto target.
Reform 2. Carbon tax, plus reduction in petrol excise duty, achieving Toronto target.

Table 4 gives the corresponding average weekly expenditure for households within the sample. The behaviour patterns are much as expected, with expenditure on household fuel increasing for both reforms, although not by as much as the price, indicating a fall in the quantity consumed. Expenditure on most other goods falls or remains fairly constant. Expenditure on petrol increases for Reform 1, but falls when the excise duty is reduced, due to cross-price effects on demand. This table relates to the FES sample underlying the simulation routine, and does not allow for the unrepresentative nature of the FES sample.

Table 5 shows the national government revenue generated by the carbon taxes and aggregate CO_2 emissions when the results from the sample have been corrected for the unrepresentative nature of the FES. Both reforms give an approximately 20 per cent reduction in CO_2 emissions, but also increase government revenue from indirect taxes by approximately 47 per cent (i.e. £16 billion).

Table 6 breaks down the total reduction in CO_2 emissions from the consumption of the CO_2-intensive goods: petrol, household fuel and transport. The expenditure predictions indicate a large reduction in consumption of household fuel and petrol, due to the relatively large price increases in these goods. Also shown are the consequent total reductions in CO_2 emissions.

TABLE 5

National Effects of Reforms 1 and 2

	Base	*Reform 1*	*Reform 2*
Change in CO_2 emissions (%)		–19.7	–19.6
Government revenue			
VAT (£m p.a.)	20,077.3	19,227.2	18,986.7
Excise (£m p.a.)	15,147.0	15,045.1	13,214.7
Carbon tax (£m p.a.)	—	17,748.1	19,629.8
Total (£m p.a.)	35,224.3	52,020.4	51,831.2
Percentage change (%)		47.7	47.1

Key: Reform 1. Carbon tax achieving Toronto target.
Reform 2. Carbon tax, plus reduction in petrol excise duty, achieving Toronto target.

TABLE 6

Changes in CO_2 Emissions by Category: Reforms 1 and 2

Per cent

	Reform 1	*Reform 2*
Household energy	–26.2	–27.0
Transport	–17.3	–18.2
Petrol	–24.5	–19.9
All other goods	–7.9	–8.3
Total	–19.7	–19.6

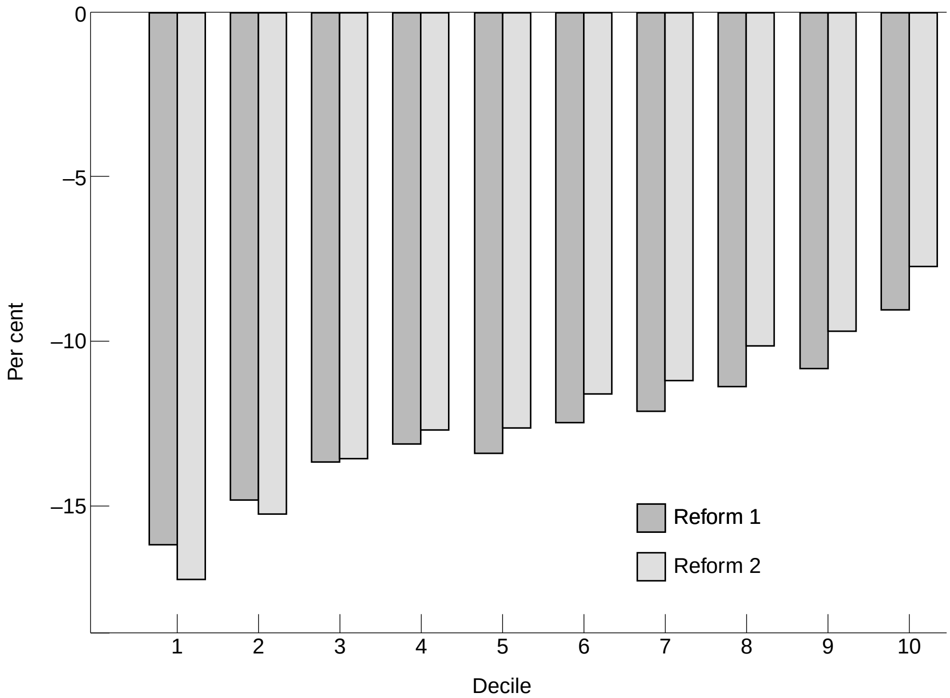
Key: Reform 1. Carbon tax achieving Toronto target.
Reform 2. Carbon tax, plus reduction in petrol excise duty, achieving Toronto target.

1. The Distributional Effects of Carbon Taxes

The greatest virtue of working with data at the household level is that it facilitates a comprehensive distributional analysis of the effects of tax changes. It is possible to break down the impact of the carbon tax rate changes for different parts of the income distribution. We measure 'welfare' by total expenditure less the indirect tax payments (including the incidence of the carbon tax). That is, we use expenditure measured at factor cost, rather than market price. This we will denote as 'disposable expenditure', and use as a measure of household welfare.

FIGURE 1

Change in Disposable Expenditure by Decile: Reforms 1 and 2



Key: Reform 1. Carbon tax achieving Toronto target.
Reform 2. Carbon tax, plus reduction in petrol excise duty, achieving Toronto target.

Figure 1 shows the average proportionate changes in disposable expenditure for members of each decile, where households have been ranked by pre-reform disposable expenditure. Disposable expenditure has clearly fallen most for those at the bottom of the income distribution in both reforms. However, Reform 1 is less regressive than Reform 2.

The drawback of Figure 1 is that it only tells us about the difference in the means of each decile group and not what is happening *within* each decile. The Atkinson and Gini inequality indices capture the change that all households experience.[2] In Table 7 we present computed inequality indices on disposable expenditure for pre- and post-reform distributions. It shows that the effect of the carbon tax on disposable expenditure becomes more unequal at all levels of inequality aversion, more so for Reform 2 than Reform 1, as would be expected given Figure 1.

TABLE 7

Inequality Indices on Disposable Expenditure: Reforms 1 and 2

	Atkinson inequality aversion parameter			*Gini*
	0.1	1.0	10.0	
Pre-reform	.02567	.26376	.85278	.38616
Post-reform: Reform 1	.02737	.28156	.87943	.39742
Post-reform: Reform 2	.02762	.28570	.88277	.39953

Key: Reform 1. Carbon tax achieving Toronto target.
Reform 2. Carbon tax, plus reduction in petrol excise duty, achieving Toronto target.

2. Comparing the Fuel and the Total Carbon Tax Effects

As noted above, one can estimate the effects of a carbon tax on household behaviour taking account only of the corresponding increased price of domestic fuels. To illustrate the importance of taking account of the total effect of a carbon tax, including the effect on the prices of manufactured (non-fuel) goods, we have estimated the impact of the fuel part of the tax separately. In Table 8 we compare the changes in expenditure on various categories of goods for a (carbon) tax on household fuels only and for the same tax rate impacting (indirectly) on all goods. We use the carbon tax rate for Reform 1 and alter no other aspects of the tax and benefits system.

We see that while the fuels-only effect of the carbon tax on the purchase of fuels is an increase in expenditure of 16 per cent, when the full effect of the tax is taken into account, the increase in expenditure is 32 per cent. There are also large differences with regard to changes in expenditure on most other categories, except food and clothing. We conclude that ignoring the impact of a carbon tax on non-fuel purchases by households will give a very distorted picture of the full effects of a carbon tax on consumer behaviour.

[2] A value of 1 indicates most inequality in distribution; a value of 0 indicates most equality in distribution (Cowell, 1977).

TABLE 8

Expenditure Changes Resulting from a Carbon Tax: Fuels Only and All Goods

Per cent

	Fuels only	*All goods*
Food	–3.1	–3.3
Beer	19.3	34.1
Wine	18.5	35.9
Spirits	1.6	4.6
Household energy	16.0	32.0
Clothing	–3.8	–4.9
Transport	–3.4	–8.5
Services	–4.0	–8.7
Petrol	12.2	1.6
Tobacco	0.8	0.0
Other goods	–3.4	–7.2
Durables	0.0	1.5
Housing	0.0	2.7

IX. REVENUE-NEUTRAL REFORMS

Reforms 1 and 2, discussed above, raise substantial tax revenues. There are many potentially beneficial policies that the Government could pursue to reduce CO_2 emissions through expenditure on goods and services: for example, construction of fuel-efficient plants, clean-up of electricity-generating plants, installation of energy-efficient appliances in housing and industry, and incentives for substitution to less fuel-intensive household durables. An important possible policy, which would reduce CO_2 emissions and be beneficial to low-income households, would be subsidised home insulation. For a discussion of the possibly great impact such measures might have on CO_2 emissions, see Jackson and Jacobs (1991). Here we do not consider such direct measures. A main advantage of indirect taxation is that it provides the correct price signal and incentive to combat externalities by individuals' and firms' behaviour. We consider uses for the revenue raised that reduce the adverse inequality effects of the carbon tax outlined in the previous section.

One possible way to maintain a revenue-neutral policy is to alter the distribution of indirect taxes towards CO_2-intensive goods. The carbon tax could replace the proportional VAT that currently operates. Table 9 shows the estimated percentage change in prices that would result from a reform using a CO_2 tax of 7.5p per kilogram and a petrol excise of 45p per gallon, with a VAT rate of zero, denoted Reform 3 in the tables. Comparing this with Reform 2 in Table 3, we see that the price of household energy has increased proportionately more than that of the other goods, since it is currently zero-rated for VAT. Similarly, the price of food has fallen much less than other prices, since the CO_2 tax is applied to all food but VAT affects only a small amount. Thus we expect the change in expenditure to be greater for households with higher income levels, which are able to substitute away from these relatively expensive goods more easily.

TABLE 9

Price Changes for Reforms 3 and 4

Per cent

	Reform 3	*Reform 4*
Household energy	91.2	91.2
Petrol	−13.5	−0.5
Durables: china	−4.5	9.8
Transport	0.3	6.1
Food	−0.3	3.4

Key: Reform 3. Carbon tax, plus reduction in petrol excise duty, plus zero VAT.
Reform 4. Carbon tax, plus reduction in petrol excise duty, plus benefits reform.

An alternative way to generate a revenue-neutral reform would be to return the increased revenue via the direct tax system. An obvious way of reducing income inequality would be to target the revenue at poorer households: for example, pensioners, low-income households and those with children. Reform 4 is a revenue-neutral change, which sets a minimum weekly expenditure per adult of £55, increases benefit to pensioner households by £7 per pensioner and to households with children by £7 per child, while maintaining the CO_2 tax at 7.5p per kilogram and petrol excise at 45p per gallon. VAT is kept at 15 per cent. The benefit reforms proposed represent a minimum income guarantee to cover necessary living expenses, approximately equating to the benefits in force in 1990. Thus those households that are affected most in terms of welfare by the high price of necessities (namely, fuel and food) are compensated by increases in income.

The price changes from Reform 4 are the same as those from Reform 2, but we expect expenditures to change more since there is an additional income effect for some households in the sample. This is confirmed in Table 10, which shows the average weekly expenditure for Reforms 3 and 4. Expenditure on household energy increases less for Reform 3, as the other goods become relatively attractive. Despite this, the fall in other prices causes the quantity of goods purchased to increase, so the reduction in CO_2 is much less than for Reforms 1 and 2. Under Reform 4, the change in the household energy expenditure is greater — 54 per cent, which compares with 39 per cent in Reform 2 — despite the 91 per cent increase in price. Here, total expenditure has increased for poorer households, where household energy is a necessity.

TABLE 10

Average Weekly Expenditure for Reforms 3 and 4

Pounds per week

	Base	*Reform 3*	*Reform 4*
Food	41.08	38.67	42.60
Beer	6.11	8.45	9.25
Wine	2.08	3.35	3.37
Spirits	1.78	2.02	2.28
Household energy	11.80	16.09	18.11
Clothing	16.58	16.53	18.47
Transport	26.70	27.21	28.05
Services	29.17	27.53	30.87
Petrol	8.29	6.99	7.38
Tobacco	5.11	4.43	5.67
Other goods	16.91	15.54	17.67
Durables	15.45	13.79	15.71
Housing	42.93	43.37	44.27
Total	223.97	223.97	243.68

Key: Reform 3. Carbon tax, plus reduction in petrol excise duty, plus zero VAT.
Reform 4. Carbon tax, plus reduction in petrol excise duty, plus benefits reform.

Table 11 summarises the aggregate effect of Reforms 3 and 4. The reforms reduce CO_2 emissions by 11–15 per cent while leaving revenue from indirect taxation approximately unaltered from the base case. his is an important finding, as it suggests that even when aggregate income is maintained, a carbon tax, through altered relative prices, will still give rise to a considerable reduction in CO_2 emissions.

Table 12 shows how the reduction in CO_2 emissions is distributed across the goods. Comparing this with Table 6, we see that for Reform 3 the reduction in CO_2 emissions from household energy is unchanged, but the reduction for transport and petrol is smaller, because the price decrease causes households to purchase more of these goods. Reform 4 has a smaller overall reduction in CO_2 emissions, since total expenditure is higher, but the reduction in emissions from petrol is greater, due to the relative price differences between the two reforms.

TABLE 11

National Effects of Reforms 3 and 4

	Reform 3	*Reform 4*
Change in CO_2 emissions (%)	–14.1	–11.3
Government revenue		
VAT (£m p.a.)	—	20,799.8
Excise (£m p.a.)	15,048.1	15,116.7
Carbon tax (£m p.a.)	19,755.8	21,645.3
Benefits (£m p.a.)	—	–21,316.7
Total (£m p.a.)	34,803.9	36,245.0
Percentage change (%)	–1.2	2.9

Key: Reform 3. Carbon tax, plus reduction in petrol excise duty, plus zero VAT.
Reform 4. Carbon tax, plus reduction in petrol excise duty, plus benefits reform.

The Distributional Effects of Carbon Taxes

Since food and household energy are necessities for poorer households (they command a high share of expenditure), the distributional effects on welfare of Reform 3 could be very severe. Figure 2 shows the average proportionate change in disposable expenditure for members of each decile, where households have been ranked into deciles of the pre-reform disposable expenditure distribution. This reform is much more regressive than those of the previous section. Reform 4 will have more favourable distributive effects, as shown in Figure 2. The poorer households in the sample have a substantial increase in total expenditure, which more than compensates them for the increased tax rates.

TABLE 12

Changes in CO_2 Emissions by Category: Reforms 3 and 4

Per cent

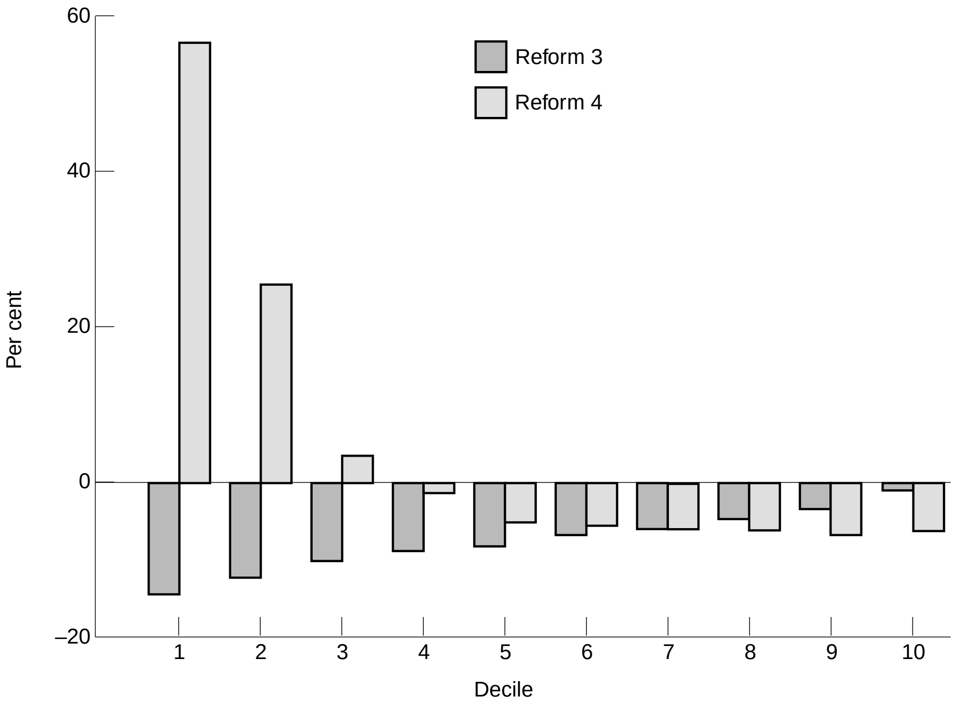
	Reform 3	*Reform 4*
Household energy	–28.7	–19.7
Transport	0.3	–5.7
Petrol	–2.5	–10.5
All other goods	–1.8	–0.2
Total	–14.1	–11.3

Key: Reform 3. Carbon tax, plus reduction in petrol excise duty, plus zero VAT.
Reform 4. Carbon tax, plus reduction in petrol excise duty, plus benefits reform.

These results are reflected in the Atkinson inequality indices given in Table 13. Reform 3 shows a large increase in inequality, larger than for Reforms 1 and 2, while Reform 4 shows a large fall in inequality at all levels of inequality aversion.

FIGURE 2

Change in Disposable Expenditure by Decile: Reforms 3 and 4



Key: Reform 3. Carbon tax, plus reduction in petrol excise duty, plus zero VAT.
Reform 4. Carbon tax, plus reduction in petrol excise duty, plus benefits reform.

X. TORONTO TARGET AND REVENUE NEUTRALITY

The reforms considered in the two previous sections illustrate two polar cases. Reforms 1 and 2 concentrated on reducing CO_2 emissions and ignored government revenue and the redistributive effect of tax reform on households. Reforms 3 and 4 gave more attention to the tax revenue generated and to the increased income inequality which may be created. This section addresses both issues: it considers a tax system that will reduce CO_2 emissions by approximately 20 per cent while having neither a sizeable impact on government revenue nor a detrimental effect on household income distribution.

TABLE 13

Inequality Indices on Disposable Expenditure: Reforms 3 and 4

	Atkinson inequality aversion parameter			*Gini*
	0.1	1.0	10.0	
Pre-reform	.02567	.26376	.85278	.38616
Post-reform: Reform 3	.02862	.29599	.88810	.40633
Post-reform: Reform 4	.02272	.22026	.74000	.36186

Key: Reform 3. Carbon tax, plus reduction in petrol excise duty, plus zero VAT.
Reform 4. Carbon tax, plus reduction in petrol excise duty, plus benefits reform.

Reform 5, which is now presented, is revenue neutral and allows for benefit adjustments on equity grounds. However, it involves a much higher carbon tax rate (£444 per tonne) to ensure the necessary reduction in CO_2 emissions. The parameters of the tax systems for Reform 5 are given in Table 2, while the expected effect on consumer prices is given in Table 14. The very high carbon tax results in a very high price increase for household energy, since there is no completely offsetting reduction in VAT or excise duty. The macroeconomic effects and possible implications for labour demand and supply are ignored.

TABLE 14

Price Changes for Reform 5

Per cent

	Reform 5
Household energy	145.9
Petrol	19.9
Durables: china	6.0
Transport	5.6
Food	2.9

Key: Reform 5. Carbon tax, plus reduction in petrol excise duty, plus benefits reform, approximately achieving Toronto target.

Table 15 gives the predicted average weekly expenditure for households under Reform 5. The reforms entail an increase in total expenditure of £20 per week, resulting from the increase in benefit payments. This causes a substantial increase in expenditure on household energy, but a 33 per cent reduction in quantity purchased and a consequent reduction in CO_2 emissions.

The overall effects of Reform 5, on CO_2 emissions and government revenue,

TABLE 15

Average Weekly Expenditure for Reform 5

Pounds per week

	Base	*Reform 5*
Food	41.08	41.14
Beer	6.11	10.63
Wine	2.08	3.96
Spirits	1.78	2.43
Household energy	11.80	19.39
Clothing	16.58	17.73
Transport	26.70	28.66
Services	29.17	30.12
Petrol	8.29	8.57
Tobacco	5.11	5.30
Other goods	16.91	16.83
Durables	15.45	14.58
Housing	42.93	44.47
Total	223.97	243.78

Key: Reform 5. Carbon tax, plus reduction in petrol excise duty, plus benefits reform, approximately achieving Toronto target.

TABLE 16

National Effects of Reform 5

	Reform 5
Change in CO_2 emissions (%)	–17.8
Government revenue	
VAT (£m p.a.)	7,420.9
Excise (£m p.a.)	17,351.3
Carbon tax (£m p.a.)	31,376.4
Benefits (£m p.a.)	–21,426.3
Total (£m p.a.)	34,722.3
Percentage change (%)	–1.4

Key: Reform 5. Carbon tax, plus reduction in petrol excise duty, plus benefits reform, approximately achieving Toronto target.

are shown in Table 16.

Under Reform 5 there is a 20 per cent increase in the price of petrol and only a 3.4 per cent increase in expenditure. This results in a reduction of 13.7 per cent in quantity, and hence corresponding CO_2 emissions, as shown in Table 17. Overall, Reform 5 yields reductions in CO_2 emissions of 17.8 per cent and is approximately revenue neutral.

The distributional impact of Reform 5 is determined by considering which households gain most from the average increase in total expenditure. Figure 3 shows the percentage change in disposable expenditure for deciles of pre-reform disposable expenditure. The bottom two deciles gain from the reforms, whilst the other households all lose approximately 5 per cent of disposable expenditure, so Reform 5 reduces the regressiveness of the current indirect tax system.

The inequality of disposable expenditure is reduced, as shown in Table 18.

TABLE 17

Changes in CO_2 Emissions by Category: Reform 5

Per cent

	Reform 5
Household energy	–33.1
Transport	–3.6
Petrol	–13.7
All other goods	–0.4
Total	–17.8

Key: Reform 5. Carbon tax, plus reduction in petrol excise duty, plus benefits reform, approximately achieving Toronto target.

TABLE 18

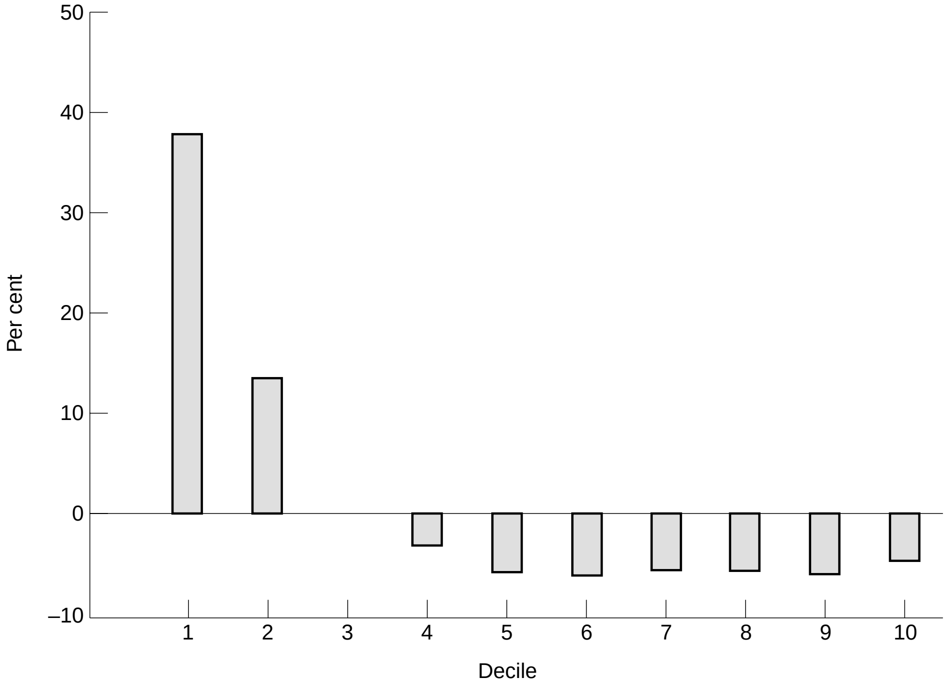
Inequality Indices on Disposable Expenditure: Reform 5

	Atkinson inequality aversion parameter			*Gini*
	0.1	1.0	10.0	
Pre-reform	.02567	.26376	.85278	.38616
Post-reform: Reform 5	.02414	.23662	.80705	.37294

Key: Reform 5. Carbon tax, plus reduction in petrol excise duty, plus benefits reform, approximately achieving Toronto target.

FIGURE 3

Change in Disposable Expenditure by Decile: Reform 5



Key: Reform 5. Carbon tax, plus reduction in petrol excise duty plus benefits reform, approximately achieving Toronto target.

XI. CONCLUSIONS

This paper illustrates the effects of introducing carbon taxes on the pattern of consumer demand, and thus production, in the economy. A carbon tax is imposed on fuels under the assumption of its complete incidence on final demand (including consumers). This is equivalent to an indirect tax reflecting the CO_2 intensity of consumer goods; thus goods that generate much CO_2 emission in production (directly and indirectly) will be taxed relatively heavily. This is in addition to the impact of the carbon tax through the direct sale of fuel to consumers. The level of CO_2 emissions for categories of consumption goods is evaluated within an input–output framework.

There are large increases in the price of some commodities, notably household energy, petrol, china, transport and, to a lesser extent, food. The price increases of the first two commodities are due primarily to the direct consumer purchase of the good, those of the others to the fossil fuel used in production of the goods for consumers. The carbon tax that reduces the UK CO_2 emissions attributable to consumer demand by 20 per cent generates a 47 per cent increase in government revenue from indirect taxes and has dramatic adverse distributional effects for low- income households within the economy.

Reforms are also considered that attempt to offset these distributional effects by increasing benefit payments to low earners. These result in a rather lower reduction in CO_2 emissions, but have positive redistributive effects in terms of welfare. It is important to note that our revenue-neutral tax reforms (i.e. where the carbon tax revenues are recycled) still give rise to considerable reductions in CO_2 emissions.

We finally consider possible tax and benefit systems that reduce CO_2 emissions but maintain revenue neutrality and attempt to offset the adverse distributional effects of the carbon tax. This reform results in a very substantially larger carbon tax but a reduction in other indirect taxes, leaving many prices almost unchanged. The exception to this is a large increase in the price of household energy. Low- income households are compensated by the increase in benefits which results in a higher disposable expenditure.

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