Carbon Taxation, Prices and Household Welfare in New Zealand

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New Zealand Treasury

Working Paper 04/23

December 2004

THE TREASURY
Kaitohutohu Kaupapa Rawa

NZ TREASURY WORKING PAPER 04/23

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MONTH/YEAR

December 2004

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ACKNOWLEDGEMENTS

We should like to thank Statistics New Zealand, in particular Jeremy Webb, for making available its monetary and physical estimates of fuel use by industry. This information is from the Statistics New Zealand Energy Flow Account report that will be published in March 2004. We are also grateful to Iris Claus for help with the Input-Output data, and Peter Wilson for comments on an earlier version.

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Abstract

This paper examines the effects on consumer prices of a range of carbon taxes in New Zealand, using information about inter-industry transactions and the use of fossil fuels by industries. The resulting effects on the welfare of different household types and total expenditure levels are examined. The excess burdens of the carbon tax are computed for the different household types. Finally, overall measures of inequality are reported.

JEL CLASSIFICATION H23 – Externalities; Redistributive Effects
H31 – Household
D57 – Input-Output Analysis

KEYWORDS Carbon tax; equivalent variations; excess burdens; inequality

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1 Introduction

In October 2002, the New Zealand Government announced its intention to introduce a charge on carbon dioxide (and fossil fuel) emissions from the year 2007. The charge forms part of the Government's policy package on climate change designed to meet New Zealand's greenhouse gas reduction target under the Kyoto Protocol. The charge will approximate international emissions prices, but will be capped at $25 per tonne of carbon dioxide. The aim of this paper is to analyse the price, welfare and inequality changes that may arise from the imposition of such a carbon tax.[1] The exact magnitude of the tax is still unknown. For this reason, the paper analyses three carbon tax rates of $7, $15 and $25 per tonne of carbon dioxide.

The analysis proceeds as follows. First, it is necessary to provide a link between a carbon tax (expressed in terms of tonnes of carbon dioxide) and the price changes of commodities; this depends on the carbon dioxide intensities of each good. These intensities in turn depend on the fossil fuels used in the production of each good and the nature of inter-industry transactions. Second, given the price changes, it is necessary to evaluate the effect on the welfare of households; this stage requires the use of a demand model. This paper uses the linear expenditure system, where the parameters vary between household types and total expenditure levels. Third, the overall evaluation of the carbon tax requires the calculation of inequality measures, involving an allowance for household composition.

Section 2 sets out the basic framework of analysis. Subsection 2.1 derives an expression for the carbon dioxide intensities of commodities. These intensities together with a carbon tax rate are then used to calculate the effective carbon tax rates on commodities and subseqent prices changes, expressions for which are derived in subsection 2.2.

Section 3 applies the framework to New Zealand. Subsection 3.1 describes the sources from which the data were gathered and the processes used to evaluate the expressions derived in section 2. Subsection 3.2 outlines the data and methodology used to analyse the demand responses of consumers. One problem relates to the different levels of aggregation used in the input-output and household demand analyses. The theory behind the various measures used to conduct the analysis is provided in Appendix B. The implied

[1] This paper does not consider the effects of such a tax on aggregate emissions. For a review of rates needed for target emissions reductions, see Pearce (1991). See also Cornwell and Creedy (1997). On changes in emissions in Australia, see Common and Salma (1992).

price and indirect tax changes for alternative carbon dioxide rates are then reported in subsection 3.3. As a partial equilibrium analysis, reductions in carbon dioxide emissions are assumed to be generated purely through consumer substitution. Hence, the possible effects of the carbon tax on the use of fuels and other intermediate inputs by industries are not modelled here.

Section 4 analyses the welfare and inequality effects arising from the three carbon tax rates. Welfare changes, measured in terms of equivalent variations, are examined for a range of household types and levels of total weekly expenditure. These welfare measures give an indication of the disproportionality of the impact at different total expenditure levels, for the household types. Overall measures of inequality are also computed for each household type and for all households combined. These use the individual as the basic unit of analysis and make use of adult equivalence scales in producing each individual's level of 'wellbeing'.

Conclusions are provided in section 5.

2 A Carbon Tax and Prices

The first stage of the analysis is to apply a carbon tax and examine its effects on consumer prices. This section derives the expressions used to calculate such price changes. A carbon tax is specified as a number of dollars per tonne of carbon generated by the production of each good. It is therefore necessary to translate from a tax specified in term of physical amounts of carbon into an equivalent tax imposed per dollar of expenditure by final consumers of each good. This is achieved through the carbon intensity of each good.

As with other studies of carbon taxes, the tax examined is actually considered to be imposed on carbon dioxide intensity, rather than carbon intensity. However, carbon content and carbon dioxide emissions are directly proportional by molecular weight, and the equivalent tax on carbon content can be obtained by multiplying the carbon dioxide tax by 44/12. Hence a tax is specified in terms of tonnes of carbon dioxide and consumer prices rise in proportion to their carbon dioxide intensity.

This intensity, defined by c_i measures the tonnes of carbon dioxide emissions per dollar of final consumption of the output from industry i. Therefore, a carbon dioxide tax of α which is placed on carbon dioxide emissions is equivalent to an *ad valorem* tax-exclusive rate on the i^{th} commodity group of τ_i, where:[2]

$$\tau_i = \alpha c_i \tag{1}$$

As the intensity is expressed in terms of each dollar's worth of the output that contributes to final demands, the total amount of carbon dioxide arising from all industries, E, is given by:

$$E = \sum_{i=1}^{n} c_i y_i = c' y \tag{2}$$

where y_i is the value of final demand for industry i for $i = 1, ..., n$. The terms c and y denote corresponding column vectors and the prime indicates transposition.

The carbon dioxide intensities depend in a direct way on the types and amounts of fossil fuels used by each industry, and the emissions per unit of those fossil fuels. However, the problem is complicated by the need to consider the total output of each industry, rather than merely the amount of that output which is consumed, that is the final demand. This problem is examined in subsection 2.1. Having obtained the equivalent tax rates, the next stage is to obtain an expression for the overall tax rate imposed on each unit of the good consumed. This is discussed in subsection 2.2.

[2] It is important to recognise that the carbon (dioxide) tax is quite different from something like a value added tax, for which the effective rate imposed on final consumers does not depend on the precise stage at which the tax's legal incidence falls, since the tax is simply passed forwards and eventually falls on consumers.

2.1 Carbon Intensities

Consider increasing the final consumption of a good by $1. The problem is to evaluate how much carbon dioxide this would involve. This increase in the final demand by $1 involves a larger increase in the gross, or total output, of the good - as well as requiring increases in the outputs of other goods. This is because intermediate goods, including the particular good of interest, are needed in the production process. The extent to which there is an increase in carbon dioxide depends also on the intermediate requirements of all goods which are themselves intermediate requirements for the particular good. Indeed, the sequence of intermediate requirements continues until it 'works itself out', that is, the additional amounts needed become negligible. This is in fact a standard multiplier process. It can be set out formally as follows.

An industry's gross output derives from both intermediate output which serves as input to other industries and final demand. Let x_{ij} denote the value of output flowing from industry i to industry j and let y_i denote the value of final demand, by consumers, for the output of industry i. The value of an industry's gross output, x_i, may therefore be expressed as the sum of intermediate and final demands:

$$x_i = \sum_j x_{ij} + y_i \tag{3}$$

The direct requirement co-efficient, a_{ij}, measures the value of output from industry i directly required to produce $1 worth of output in industry j. Hence:

$$a_{ij} = \frac{x_{ij}}{x_i} \tag{4}$$

Using (4) to write $x_{ij} = a_{ij} x_i$ and substituting the resulting expression into equation (3) gives gross output as:

$$x_i = \sum_j a_{ij} x_i + y_i \tag{5}$$

Let x and y denote the n-element vectors of x_i and y_i respectively. Further, let A denote the $(n \times n)$ matrix of the direct requirement coefficients, a_{ij}. These definitions enable the system of n equations described in equation (5) to be expressed in matrix notation as:

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

Continuous substitution for x on the right-hand side of equation (6) produces the following geometric sequence:

$$\begin{aligned} x &= A[Ax + y] + y \\ x &= A[A\{Ax + y\} + y] + y \\ x &= [I + A + A^2 + A^3 + \ldots + A^{\infty} x]y \end{aligned} \tag{7}$$

If the condition $\lim_{n\to\infty} A^n = 0$ is satisfied, the system is productive and the non-negative solution is:[3]

$$x = (1 - A)^{-1} y \qquad (8)$$

and $(I - A)^{-1}$ is the matrix multiplier required.

Let F denote the $(n \times k)$ matrix of energy requirements (in PJs) for n industries across k fossil fuel types. Let e denote the k-element vector of CO_2 emissions (tonnes of carbon dioxide) per unit of energy (PJ) associated with each of the k fossil fuels.

Multiplying the transpose of the e vector by the transpose of the F matrix gives the following row vector which contains the carbon dioxide emissions per unit of gross output from each industry:

$$e'F' = [e_1 \ldots\ldots e_k] \begin{bmatrix} f_{11} & \cdots & f_{n1} \\ \vdots & & \vdots \\ f_{1k} & \cdots & f_{nk} \end{bmatrix} \qquad (9)$$

Total carbon dioxide emissions, E, can then be obtained by post-multiplying the above row vector by the column vector of gross output, x :

$$\begin{aligned} E &= e'F'x \\ E &= [e'F'(1 - A)^{-1}]y \end{aligned} \qquad (10)$$

This may be compared with (2) above. The term in square brackets gives the row vector, c', of the carbon dioxide intensities:

$$c' = e'F'(I - A)^{-1} \qquad (11)$$

This expression can then be used together with a selected carbon tax rate to calculate the effective carbon tax rates given by equation (1).

The expression in (11) is in fact a simplified form of that obtained by Proops et al (1993) and Symons et al (1994) and used by Cornwell and Creedy (1997). The present analysis abstracts from carbon dioxide emissions arising directly from the consumption of goods and services, which are small compared with those arising from production.[4]

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[3] This is given from the solution to the geometric matrix series $S = I + A + A^2 + \ldots = (I - A)^{-1}$, which must be non-negative given that all elements of A are either zero or positive. For the system to be productive it is not merely sufficient for (6) to have a solution. The convergence requirement is equivalent to the Hawkin-Simons conditions.

[4] For further applications of this approach, see also Creedy and Cornwell (1995, 1996, 1997) and Creedy and Martin (2000a, 2000b).

2.2 Effective Tax Rates

The carbon tax is imposed in addition to pre-existing indirect taxes. Hence it is necessary to obtain an expression for the post-carbon tax equivalent indirect tax rates. Let p_0 denote the tax-exclusive price of commodity i , where the subscript has been dropped for convenience. Prior to the imposition of the carbon tax, the existing *ad valorem* tax rate is t and therefore the tax-inclusive price of commodity i, p_1, is defined by:

$$p_1 = p_o(1+t) \tag{12}$$

The carbon (dioxide) tax is effectively a tax on final consumption at the rate, $\tau_i = \alpha c_i$, which is the resulting proportional increase in the price of the good. Hence, the new tax-inclusive price of commodity i , p_2, is given by:

$$\begin{aligned} p_2 &= p_1(1+\tau) \\ p_2 &= p_0(1+t)(1+\tau) \end{aligned} \tag{13}$$

The overall effective *ad valorem* tax rate on commodity i , t^* , may therefore be calculated from the expression:

$$\begin{aligned} t^* &= (1+t)(1+\tau)-1 \\ t^* &= t+\tau(1+t) \end{aligned} \tag{14}$$

In the following analysis the effects of shifting from t to t^* are examined. The term τ, as the effective carbon tax on consumption, measures the proportional price increase for each good.

3 Application to New Zealand

This section outlines the data and approach used to evaluate the expressions, derived in the previous section, for New Zealand. Subsection 3.1 describes the data used to determine the carbon dioxide intensity, c_i of the output from each of New Zealand's industries. Subsection 3.2 describes the data used to analyse the demand responses and welfare changes arising from the imposition of the carbon tax. Section 3.3 reports the effective tax rates and price changes arising from alternative carbon dioxide tax rates.

3.1 Fuel use and carbon content

The "Inter Industry Study of 1996" from New Zealand's System of National Accounts provided inter-industry flows in value terms for a 49 industry group classification (IGC).[5] These flows were divided by each industry's gross output to produce the direct requirement coefficients which were then collected to form the (49×49) A matrix.

By subtracting each industry's intermediate output from their gross output, the National Accounts were also used to compile the 49-element y vector of final demands.

The F matrix was constructed from New Zealand's Energy Flow Accounts which provided the energy use arising from fossil fuels, expressed in physical terms (PJs), for the year ended March 1996 based on the Energy Account Industry Classification (EAIC). The translation between the Energy Account Industry Classification (EAIC) and the 49 industry group classification (IGC) which was used for the analysis is provided in Table A1. Only those fuels for which at least one industry recorded a positive expenditure were incorporated, which provided nine fossil fuels for analysis. Table A2 provides information about the demands for these fuels which are expressed in physical terms and based on the 49 industry group classification (IGC). Dividing these figures by each industry's gross output provided the required elements of the (49×9) F matrix.

Compiling the 9-element e vector of carbon dioxide emissions entailed obtaining data from multiple sources. Table 1 outlines the carbon dioxide emission factors for each of the nine fossil fuels analysed, along with their sources.

[5] This is the most recent year for which the data are available.

***Table 1 – Carbon Dioxide Emission Factors:* Tonnes / PJ**

Fuel	CO_2 Emissions	Source
Coal	90,010	Statistics NZ (1993, Table 4.5, p21)
Lignite	95,200	Statistics NZ (1993, Table 4.5, p21)
Crude Petroleum	65,100	Taylor et al (1993, Table 6.6, p35)
Natural Gas	52,600	MED (2003, Table A.1.1, p114)
LPG	60,400	Baines (1993, Table 5.7, p30)
Petrol	66,600	Baines (1993, Table 6.6, p35)
Diesel	68,700	Baines (1993, Table 6.6, p35)
Fuel Oil	73,700	Baines (1993, Table 6.6, p35)
Aviation Fuels & Kerosene	68,700	Baines (1993, Table 6.6, p35)

The resulting values of e, F and A were used to calculate the 49-element c vector of carbon dioxide intensities, using the expression $c' = e'F'(I-A)^{-1}$ derived in subsection 2.1. The results of this calculation are provided in Table A3.

It is not surprising that petroleum and industrial chemical manufacturing (industry no. 18), which demands the greatest quantity of fuel across all industries, recorded by far the highest carbon content of 3.64 tonnes of carbon dioxide per dollar of gross output. Rubber, plastic and other chemical product manufacturing (industry no. 19) and basic metal manufacturing (industry no. 21) which respectively demand the largest quantities of natural gas and coal record similarly high carbon contents of 1.83 and 1.40 tonnes of carbon dioxide per dollar of gross output. The only other industry to record a carbon content in excess of 1, was electricity generation and supply (industry no. 26) with 1.21.

3.2 Household Demands

The first stage in the analysis of the impact of price changes on households is to estimate the relationships between budget shares and total household expenditure for a range of household types. Household expenditure data from the Household Economic Survey (HES) for the years 1995, 1996, 1997, 1998 and 2001 were adjusted to 2001 prices using the consumer price index (CPI).[6] Over this period there were very few changes in indirect taxes. The surveys were then pooled to form one large database.

Table 2 shows the household types used.[7] In each case households were further divided into smoking (S) and non-smoking (NS) households; a positive weekly expenditure on tobacco (group 17 in Table 3) was sufficient for the household to be designated as a smoking household. The division into smoking and non-smoking households, for examination of all commodity groups, was found substantially to improve the fit of most of the budget share relationships.[8] Table 2 also gives the arithmetic mean total weekly household expenditure for each household type.

It was necessary to express all existing indirect taxes in terms of a tax-exclusive *ad valorem* tax rate. While this is straightforward for most commodity groups, for which only GST applies, the translation is more complex where an excise tax is also imposed, as these are typically based on units of the commodity rather than values.

[6] Unfortunately, no surveys were carried out in 1999, 2000. or 2002.
[7] For the first two types, the age refers to that of the 'head' of the household.
[8] This is the relationship in equation (B8) in the Appendix.

It was not possible, mainly because of estimation difficulties, to use all the separate and highly detailed HES commodity categories. Instead, these were consolidated into 22 commodity groups. Table 3 shows the commodity groups used and the effective *ad valorem* tax-exclusive percentage rates, at 2001. The rates shown in Table 3 were taken from Young (2002). Where several HES categories were combined, the effective rates also required the computation of a weighted average of the individual components. Table 3 clearly indicates the high effective rates on petrol, cigarettes and tobacco and alcohol. These high rates are typically rationalised on merit good and externality grounds.[9]

The demand responses were calculated using the 22 commodity group classification discussed above. However, the price changes arising from the carbon tax are given for a 49 industry group classification. The calculated price changes cannot therefore be directly used to evaluate the demand responses and welfare changes. Table A4 provides the translation between the two classifications.

It may be thought that the demand model, and welfare changes, should explicitly allow for external effects. For example, suppose there is a small community in which some people hate noise and smoke, while others play loud music and burn domestic rubbish in their gardens. The people who hate smoke and noise are forced to dry their washing indoors and insulate their houses with double glazing. Taxes on smoke and noise mean that budget allocations change - those who do not need to spend on indoor drying and insulation change their allocation away from these goods.[10] Those who made noise and smoke have to spend money on devices to avoid creating the externalities, and adjust their allocations elsewhere because of income effects. Any attempt to evaluate the welfare and distributional effects of such taxes must allow for these external effects on consumption patterns and thus of course utility functions. However, the case considered in this paper is closer to a situation in which no one makes noise or smoke, but households use electricity and gas for heating and cooking. However, there are no smoke-belching coal-fired electricity generating plants near houses, and the people in the community are not aware (since it is far from visible) that their use of electricity produces effects on the air of other communities or on the ozone layer which may affect them eventually, but whose effects are remote and not evident. A tax on carbon emissions produces differential price changes for all goods according to their carbon intensities. The cleaner air elsewhere does not enter utility functions. An evaluation of the welfare and distributional effects of the tax is not subject the problems of the first case above. The government, however, believes that there are benefits to being part of an international agreement, and believes that some other communities will benefit from cleaned air. Its decision to impose the tax involves a balancing of the costs imposed by the price changes against the overall gains from emissions reductions.

[9] For a case study of alcohol, see Barker (2002).

[10] And, in a partial equilibrium context, only the prices of these two previously untaxed goods change.

Table 2 – Household Categories

No.	Household Type	Number of Households		Mean Weekly Expenditure	
		Smoking	Non-Smoking	Smoking	Non-Smoking
1	65+ single	161	1282	267	274
2	65+ couple	224	1191	498	540
3	Single - no children	384	1098	406	437
4	Single - 1 child	148	239	400	403
5	Single - 2 children	148	181	428	438
6	Single - 3 children	59	75	468	475
7	Single - 4+ children	33	39	501	539
8	Couple - no children	966	2036	690	766
9	Couple - 1 child	381	643	668	763
10	Couple - 2 children	435	916	707	896
11	Couple - 3 children	207	458	805	844
12	Couple - 4+ children	98	195	673	822
13	3 adults - no children	319	456	975	992
14	3 adults - 1 child	122	157	898	1038
15	3 adults - 2+ children	117	134	826	920
16	4+ adults - no children	179	192	1311	1282
17	4+ adults - 1 child	65	60	1110	1129
18	4+ adults - 2+ children	47	47	1070	925

Table 3 – Commodity Groups and Tax Rates

No.	Tax Rate (%)	Commodity Group	HES Categories
1	12.5	Food	00-08
2	12.5	Food outside home	10
3	0	Rent	11
4	12.5	Pay to Local Authorities	13
5	12.5	House maintenance	15-17
6	12.5	Domestic fuel and power	18-30
7	12.5	Household equipment	31-32
8	12.5	Furnishings	33-36
9	12.5	Household services	37-38
10	12.5	Adult clothing	39-40,42-45,47-48
11	12.5	Children's clothing	41,46
12	12.5	Public transport in NZ	49
13	0	Overseas travel	50
14	7.05445	Vehicle purchase	51-53
15	71.776	Petrol etc	54-59
16	12.5	Vehicle supplies, parts etc	60-69
17	239.845	Cigarettes and tobacco	70-73
18	46.8191	Alcohol	74-85
19	12.5	Medical, cosmetic etc	86-88
20	12.5	Services	94-101
21	6.25	Recreational vehicles	58
22	12.5	Other expenditure	89-91,102

3.3 Taxes and Prices

In view of the uncertainly regarding the precise charge on carbon dioxide that will come into effect from the year 2007, three carbon tax rates of $7, $15 and $25 per tonne of carbon dioxide are examined here. As the values of final demands are measured in thousands of dollars, a tax rate of, for example, $7 translates into a value of α of 0.007.

The left side of Table 4 shows the effective carbon tax rates for 22 commodity groups. These calculations were made for each of the three carbon tax rates, expressed in thousands of dollars per tonne of carbon dioxide. Displayed on the right side of Table 4 are the new effective *ad valorem* tax rates. When wishing to analyse the effects of the carbon taxes on commodity prices, the values of t^* are not directly comparable because the existing *ad valorem* tax rates, t, differ across the commodity groups. Attention is therefore turned to the effective carbon tax rate, τ.

For each of the three carbon tax rates, petrol etc (commodity group 15) faces by far the greatest price increase. Figure 1 shows the expected budget shares of total expenditure devoted to petrol, for a range of total weekly household expenditure levels, by households with two adults and two children. These are based on estimates of the budget share relationship specified in Appendix B. The inverse relationship between weekly expenditure and budget shares for both smoking and non-smoking households is indicative of the majority of types of household and shows that low-income earners spend a proportionately greater amount of their budget on petrol than high income earners. Similarly, domestic fuel and power (commodity group 6) and food (commodity group 1), both of which face substantial price rises as a result of the carbon tax, also form higher proportions of the budgets of lower-income earners. This is illustrated in Figures 2 and 3, which replicate the inverse relationship, found above, between budget shares and total expenditure.

These findings suggest that the carbon tax may have a proportionately higher impact on those housholds with relatively lower total household expenditure, for any given household type. However, the effect of a carbon tax is not unambiguous. The price of food consumed outside the home (commodity group 2) also rises substantially, and in this case higher-income earners spend a proportionately larger amount of their budgets on this good. Overseas travel (commodity group 13) incurs the fourth largest price increase, and its budget share increases with total expenditure.[11]

Following petrol, household servcies (commodity group 9) incurs the second largest price increase. This commodity group directly corresponds to the rubber, plastic and other chemical product manufcaturing industry (industry no. 19), whose output has the second highest carbon content.

[11] The question arises of how overseas travel should be treated: there are grounds for continuing to treat the effective tax on this commodity group as zero. However, sensitivity analyses showed that the results are not significantly affected by setting this price change to zero.

Table 4 – Effective Carbon Tax Rates (τ) and New Effective* Ad Valorem *Tax Rates (t^*)

No.	Commodity Group	τ			t^*		
		α = .007	α = .015	α = .025	α = .007	α = .015	α = .025
1	Food	0.0036	0.0077	0.0128	0.1290	0.1336	0.1394
2	Food outside home	0.0033	0.0070	0.0117	0.1287	0.1329	0.1382
3	Rent	0.0011	0.0024	0.0040	0.0011	0.0024	0.0040
4	Pay to Local Authorities	0.0012	0.0026	0.0043	0.1264	0.1279	0.1299
5	House maintenance	0.0015	0.0031	0.0052	0.1266	0.1285	0.1309
6	Domestic fuel and power	0.0077	0.0165	0.0275	0.1337	0.1436	0.1559
7	Household equipment	0.0025	0.0054	0.0090	0.1278	0.1311	0.1352
8	Furnishings	0.0020	0.0043	0.0071	0.1272	0.1298	0.1330
9	Household services	0.0128	0.0275	0.0459	0.1394	0.1560	0.1766
10	Adult clothing	0.0018	0.0038	0.0063	0.1270	0.1293	0.1321
11	Children's clothing	0.0018	0.0038	0.0063	0.1270	0.1293	0.1321
12	Public transport in NZ	0.0039	0.0084	0.0140	0.1294	0.1345	0.1408
13	Overseas travel	0.0060	0.0129	0.0216	0.0060	0.0129	0.0216
14	Vehicle purchase	0.0016	0.0034	0.0056	0.0722	0.0741	0.0765
15	Petrol etc	0.0213	0.0456	0.0760	0.7543	0.7961	0.8483
16	Vehicle supplies, parts etc	0.0016	0.0034	0.0056	0.1268	0.1288	0.1313
17	Cigarettes and tobacco	0.0021	0.0046	0.0077	2.4057	2.4140	2.4245
18	Alcohol	0.0019	0.0041	0.0069	0.4710	0.4743	0.4783
19	Medical, cosmetic etc	0.0010	0.0022	0.0037	0.1262	0.1275	0.1292
20	Services	0.0009	0.0019	0.0032	0.1260	0.1272	0.1286
21	Recreational vehicles	0.0016	0.0034	0.0056	0.0642	0.0661	0.0685
22	Other expenditure	0.0024	0.0051	0.0085	0.1277	0.1308	0.1346

Figure 1 – Budget Share Allocated to Petrol by Household Type 10

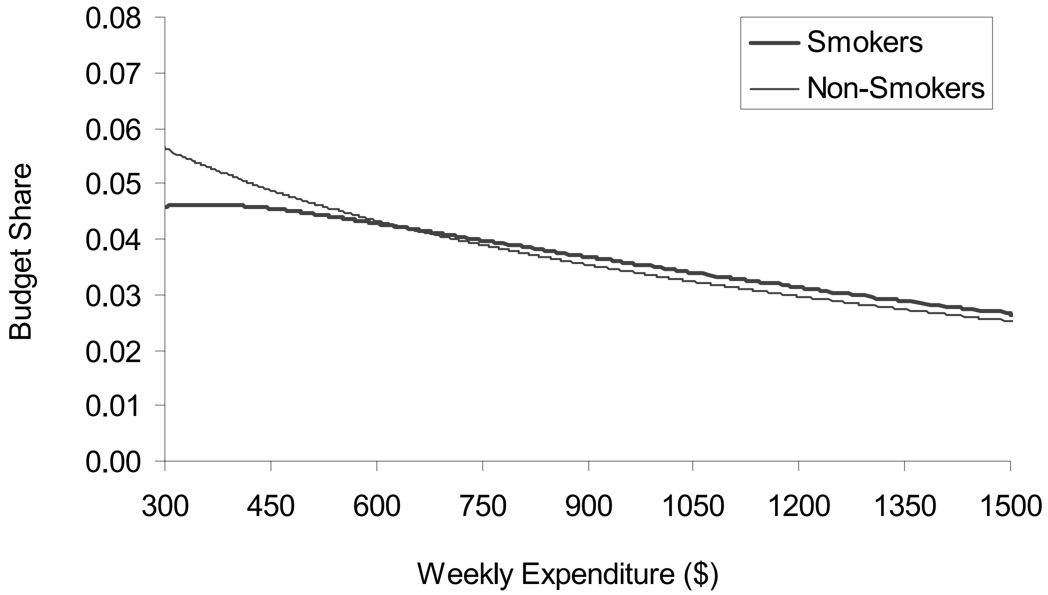
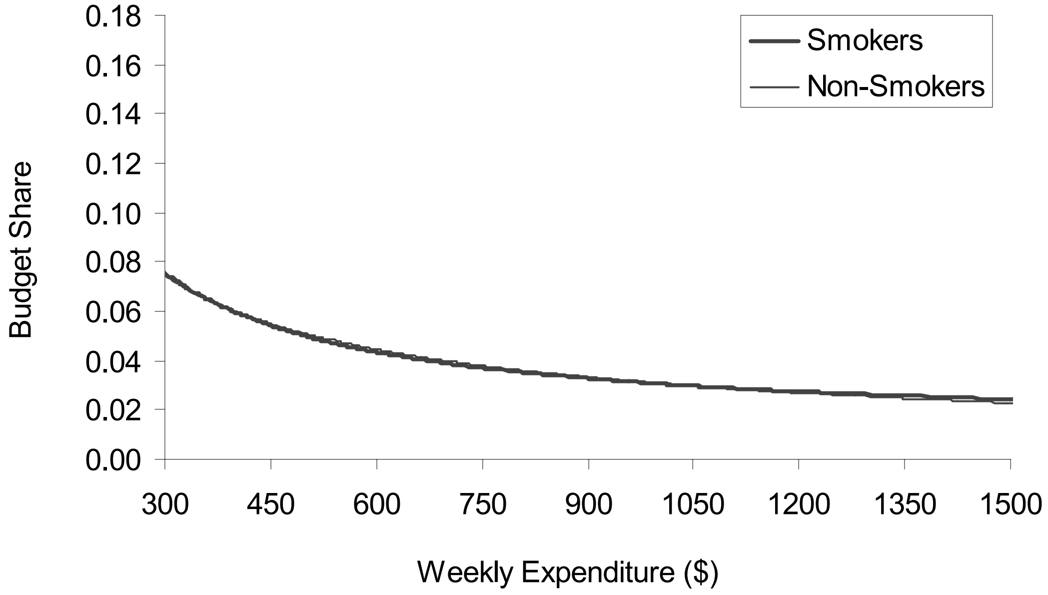


Figure 2 – Budget Share Allocated to Food by Household Type 10

Figure 3 – Budget Share Allocated to Domestic Fuel and Power by Household Type 10



4 Welfare Analysis of a Carbon Tax

This section examines the effects of a carbon tax on the welfare of different household types at different levels of total weekly expenditure, along with overall inequality measures. A summary of the theory behind these welfare measures and their computation may be found in Appendix B.

4.1 Welfare Changes

Tables 5 and 6 summarise the welfare changes that arise from each of the three carbon tax rates. The analysis was conducted using ten expenditure levels ranging from $200 to $1400, though for convenience only three values are shown in the tables for each of the eighteen household types. The welfare changes for those households who recorded a positive weekly expenditure on tobacco are provided in Table 5, while Table 6 outlines the welfare changes for non-smoking households. The equivalent variation, EV, is given together with its ratio to total expenditure, EV/y.[12] The tables show that the welfare loss ranges from approximately 0.38 percent of total expenditure in the case of a $7 carbon tax to 1.4 percent in the case of a $25 carbon tax.

The relationship between EV/y and y provides an indication of the disproportionality of the welfare impact of the carbon tax within each household type. A rising profile may be described as progressive. Within each household type, the profile of EV/y with y is similar for each of the three carbon tax rates.

For nine non-smoking households and six smoking household types, the ratio EV/y decreases with y. This suggests that the carbon tax may be slightly more regressive among non-smoking households. However, for the majority of household types, the carbon tax proves to be neither strictly regressive nor progressive. The column adjacent to EV/y gives the increase in tax paid per week, ΔT. The tables show that for any given carbon tax rate and level of expenditure, the increase in tax paid does not vary substantially between household types.

The marginal excess burden of the carbon tax, MEB, is the difference between the equivalent variation and the increase in tax paid, $MEB = EV - \Delta T$. Households, both smoking and non-smoking, with low to moderate expenditure levels incur similar excess burdens independent of type. However among those households (smoking and non-smoking) with high levels of weekly expenditure, three groups incur significantly higher marginal excess burdens.

The burdens incurred by households with one child rise with expenditure at a greater rate than the burdens incurred by households with no children. Figure 4 compares the marginal excess burdens that arise from a $25 carbon tax incurred by households with one child and those with none, across one and two adult smoking households.

[12] As shown in Appendix B, this ratio is equal to the percentage change in a money metric utility measure, when pre-change prices are used as reference prices.

Table 5 – Welfare Changes for Smoking Households

HH Type	y	$7 EV	EV/y	ΔT	$15 EV	EV/y	ΔT	$25 EV	EV/y	ΔT
1	300	1.06	0.0035	0.89	2.27	0.0076	1.91	3.76	0.0125	3.17
	600	1.95	0.0032	1.65	4.17	0.0069	3.54	6.91	0.0115	5.86
	1000	3.28	0.0033	2.59	7.02	0.0070	5.53	11.63	0.0116	9.17
2	300	1.21	0.0040	1.01	2.59	0.0086	2.16	4.29	0.0143	3.57
	600	2.23	0.0037	1.90	4.76	0.0079	4.07	7.89	0.0132	6.73
	1000	3.65	0.0037	3.02	7.81	0.0078	6.44	12.94	0.0129	10.67
3	300	1.10	0.0037	0.92	2.35	0.0078	1.96	3.89	0.0130	3.24
	600	2.09	0.0035	1.76	4.48	0.0075	3.76	7.42	0.0124	6.22
	1000	3.42	0.0034	2.81	7.32	0.0073	6.00	12.12	0.0121	9.93
4	300	1.10	0.0037	0.95	2.35	0.0078	2.03	3.89	0.0130	3.37
	600	1.96	0.0033	1.69	4.19	0.0070	3.62	6.94	0.0116	5.99
	1000	3.50	0.0035	2.74	7.49	0.0075	5.85	12.39	0.0124	9.67
5	300	1.11	0.0037	0.95	2.37	0.0079	2.03	3.92	0.0131	3.36
	600	2.09	0.0035	1.77	4.48	0.0075	3.78	7.41	0.0124	6.25
	1000	3.71	0.0037	2.91	7.92	0.0079	6.21	13.10	0.0131	10.26
6	300	1.11	0.0037	0.94	2.38	0.0079	2.01	3.93	0.0131	3.33
	600	1.96	0.0033	1.67	4.20	0.0070	3.58	6.97	0.0116	5.93
	1000	3.28	0.0033	2.55	7.02	0.0070	5.45	11.63	0.0116	9.03
7	300	0.82	0.0027	0.81	1.75	0.0058	1.73	2.90	0.0097	2.86
	600	2.07	0.0035	1.71	4.43	0.0074	3.65	7.33	0.0122	6.03
	1000	3.50	0.0035	2.79	7.47	0.0075	5.95	12.35	0.0124	9.83
8	300	1.25	0.0042	1.03	2.67	0.0089	2.20	4.42	0.0147	3.64
	600	2.23	0.0037	1.91	4.77	0.0080	4.09	7.91	0.0132	6.77
	1000	3.38	0.0034	2.99	7.24	0.0072	6.39	12.00	0.0120	10.59
9	300	1.22	0.0041	1.02	2.61	0.0087	2.18	4.33	0.0144	3.60
	600	2.26	0.0038	1.91	4.83	0.0080	4.07	7.99	0.0133	6.74
	1000	3.62	0.0036	3.03	7.73	0.0077	6.48	12.81	0.0128	10.73
10	300	1.28	0.0043	1.02	2.72	0.0091	2.17	4.51	0.0150	3.58
	600	2.21	0.0037	1.91	4.73	0.0079	4.07	7.83	0.0131	6.74
	1000	3.48	0.0035	3.00	7.44	0.0074	6.42	12.34	0.0123	10.64
11	300	1.44	0.0048	1.13	3.08	0.0103	2.42	5.10	0.0170	4.01
	600	2.34	0.0039	2.02	5.01	0.0084	4.33	8.31	0.0138	7.17
	1000	3.43	0.0034	3.01	7.36	0.0074	6.44	12.21	0.0122	10.68
12	300	1.30	0.0043	1.04	2.78	0.0093	2.21	4.59	0.0153	3.66
	600	2.40	0.0040	2.03	5.14	0.0086	4.34	8.52	0.0142	7.18
	1000	3.59	0.0036	3.12	7.69	0.0077	6.68	12.76	0.0128	11.08
13	300	1.17	0.0039	0.91	2.49	0.0083	1.93	4.11	0.0137	3.19
	600	2.29	0.0038	1.92	4.90	0.0082	4.10	8.10	0.0135	6.78
	1000	3.57	0.0036	3.09	7.64	0.0076	6.60	12.66	0.0127	10.94
14	300	1.46	0.0049	1.20	3.12	0.0104	2.56	5.16	0.0172	4.24
	600	2.41	0.0040	2.06	5.15	0.0086	4.40	8.53	0.0142	7.29
	1000	3.56	0.0036	3.08	7.62	0.0076	6.59	12.63	0.0126	10.93
15	300	1.04	0.0035	0.77	2.22	0.0074	1.65	3.66	0.0122	2.72
	600	2.39	0.0040	1.88	5.10	0.0085	4.02	8.43	0.0140	6.64
	1000	3.87	0.0039	3.25	8.28	0.0083	6.95	13.71	0.0137	11.50
16	300	1.16	0.0039	1.15	2.48	0.0083	2.46	4.11	0.0137	4.08
	600	2.53	0.0042	2.12	5.41	0.0090	4.53	8.95	0.0149	7.51
	1000	3.70	0.0037	3.21	7.92	0.0079	6.87	13.13	0.0131	11.38

17	300	1.36	0.0045	1.05	2.90	0.0097	2.22	4.79	0.0160	3.66
	600	2.66	0.0044	2.19	5.69	0.0095	4.67	9.40	0.0157	7.71
	1000	4.21	0.0042	3.56	8.99	0.0090	7.60	14.89	0.0149	12.57
18	300	1.46	0.0049	1.20	3.12	0.0104	2.57	5.16	0.0172	4.25
	600	2.53	0.0042	2.16	5.41	0.0090	4.61	8.96	0.0149	7.64
	1000	3.89	0.0039	3.33	8.33	0.0083	7.11	13.79	0.0138	11.78

Table 6 – Welfare Changes for Non-Smoking Households

HH		$7			$15			$25		
Type	y	EV	EV / y	ΔT	EV	EV / y	ΔT	EV	EV / y	ΔT
1	300	1.11	0.0037	0.98	2.38	0.0079	2.10	3.94	0.013	3.48
	600	2.03	0.0034	1.80	4.34	0.0072	3.85	7.19	0.012	6.38
	1000	3.35	0.0034	2.82	7.17	0.0072	6.04	11.89	0.012	10.01
2	300	1.21	0.0040	1.07	2.58	0.0086	2.28	4.27	0.014	3.78
	600	2.22	0.0037	1.96	4.76	0.0079	4.20	7.88	0.013	6.96
	1000	3.44	0.0034	3.08	7.37	0.0074	6.60	12.23	0.012	10.93
3	300	1.16	0.0039	1.01	2.48	0.0083	2.16	4.11	0.014	3.57
	600	2.03	0.0034	1.79	4.34	0.0072	3.84	7.19	0.012	6.36
	1000	3.03	0.0030	2.67	6.50	0.0065	5.71	10.80	0.011	9.48
4	300	1.15	0.0038	1.01	2.46	0.0082	2.16	4.07	0.014	3.58
	600	2.01	0.0034	1.74	4.31	0.0072	3.72	7.14	0.012	6.16
	1000	3.43	0.0034	2.61	7.34	0.0073	5.59	12.15	0.012	9.25
5	300	1.12	0.0037	1.01	2.40	0.0080	2.17	3.99	0.013	3.59
	600	2.08	0.0035	1.78	4.45	0.0074	3.80	7.36	0.012	6.28
	1000	4.25	0.0043	3.07	9.08	0.0091	6.54	14.99	0.015	10.79
6	300	1.05	0.0035	0.93	2.25	0.0075	1.98	3.74	0.013	3.28
	600	2.09	0.0035	1.79	4.47	0.0075	3.83	7.39	0.012	6.32
	1000	4.11	0.0041	3.17	8.77	0.0088	6.77	14.46	0.015	11.15
7	300	1.15	0.0038	1.01	2.45	0.0082	2.17	4.06	0.014	3.59
	600	1.99	0.0033	1.80	4.26	0.0071	3.86	7.07	0.012	6.40
	1000	3.05	0.0031	2.65	6.54	0.0065	5.66	10.85	0.011	9.38
8	300	1.26	0.0042	1.10	2.68	0.0089	2.36	4.44	0.015	3.90
	600	2.30	0.0038	2.02	4.92	0.0082	4.31	8.16	0.014	7.14
	1000	3.44	0.0034	3.08	7.36	0.0074	6.59	12.21	0.012	10.93
9	300	1.31	0.0044	1.14	2.81	0.0094	2.43	4.64	0.016	4.02
	600	2.31	0.0039	2.02	4.94	0.0082	4.31	8.19	0.014	7.14
	1000	3.49	0.0035	3.03	7.47	0.0075	6.48	12.38	0.012	10.75
10	300	1.33	0.0044	1.13	2.84	0.0095	2.42	4.69	0.016	4.00
	600	2.31	0.0038	2.01	4.93	0.0082	4.30	8.18	0.014	7.12
	1000	3.48	0.0035	3.07	7.44	0.0074	6.57	12.34	0.012	10.89
11	300	1.31	0.0044	1.15	2.80	0.0093	2.46	4.63	0.015	4.07
	600	2.30	0.0038	2.01	4.92	0.0082	4.30	8.16	0.014	7.12
	1000	3.44	0.0034	3.05	7.37	0.0074	6.53	12.22	0.012	10.83
12	300	1.30	0.0043	1.10	2.79	0.0093	2.34	4.61	0.015	3.88
	600	2.26	0.0038	1.96	4.83	0.0081	4.20	8.01	0.013	6.96
	1000	3.51	0.0035	3.00	7.51	0.0075	6.42	12.46	0.013	10.64
13	300	1.27	0.0042	1.07	2.71	0.0090	2.29	4.49	0.015	3.78
	600	2.41	0.0040	2.07	5.16	0.0086	4.43	8.53	0.014	7.33
	1000	3.66	0.0037	3.24	7.83	0.0078	6.94	12.98	0.013	11.50
14	300	1.51	0.0050	1.23	3.21	0.0107	2.63	5.32	0.018	4.35
	600	2.52	0.0042	2.17	5.38	0.0090	4.65	8.92	0.015	7.69
	1000	3.68	0.0037	3.24	7.87	0.0079	6.93	13.05	0.013	11.49
15	300	1.22	0.0041	1.01	2.61	0.0087	2.15	4.32	0.014	3.56
	600	2.38	0.0040	2.03	5.09	0.0085	4.34	8.42	0.014	7.17
	1000	3.74	0.0037	3.19	8.00	0.0080	6.83	13.26	0.013	11.31
16	300	1.27	0.0042	1.11	2.72	0.0091	2.37	4.51	0.015	3.93
	600	2.46	0.0041	2.07	5.25	0.0088	4.43	8.70	0.015	7.33
	1000	3.71	0.0037	3.20	7.94	0.0079	6.85	13.15	0.013	11.34

HH Type	y	$7 EV	EV/y	ΔT	$15 EV	EV/y	ΔT	$25 EV	EV/y	ΔT
17	300	1.40	0.0047	1.16	2.98	0.0099	2.47	4.92	0.016	4.08
	600	2.50	0.0042	2.11	5.34	0.0089	4.52	8.83	0.015	7.47
	1000	3.81	0.0038	3.22	8.15	0.0081	6.90	13.50	0.014	11.42
18	300	1.67	0.0056	1.41	3.57	0.0119	3.01	5.91	0.020	4.99
	600	2.66	0.0044	2.31	5.70	0.0095	4.93	9.44	0.016	8.17
	1000	3.87	0.0039	3.35	8.27	0.0083	7.16	13.72	0.014	11.87

Relative to no children and independent of the number of adults, the addition of a child clearly increases a household's marginal excess burden at the higher total weekly expenditure levels.

Single adult, relative to multi-adult households with higher total expenditure levels, are similarly more adversely affected by the carbon tax. Figure 5 shows the marginal excess burdens incurred by single-adult and multi-adult households with no children when a $25 carbon tax is imposed. From multi-adult to single households, the marginal excess burden clearly tilts upwards over higher levels of weekly total expenditure. This result holds regardless of the number of children in the household.

When total expenditure levels exceed $600 per week, the marginal excess burdens incurred by couples where the head of the household is aged over 65 (household type 2) are substantially greater than those incurred by couples where both are aged under 65 (household type 8). Figure 6 compares the marginal excess burdens between these two smoking household types and shows that the two lines begin to diverge at the expenditure level of $600 per week in the case of a $25 carbon tax.

The marginal welfare cost of a tax, defined as $MWC = MEB / \Delta T$, measures the marginal excess burden per dollar of additional tax revenue. For all three carbon taxes, the variation in this measure is very similar and lies between approximately 18 and 25 cents per dollar of additional tax revenue.

Figure 4 – Marginal Excess Burdens: The Addition of a Child

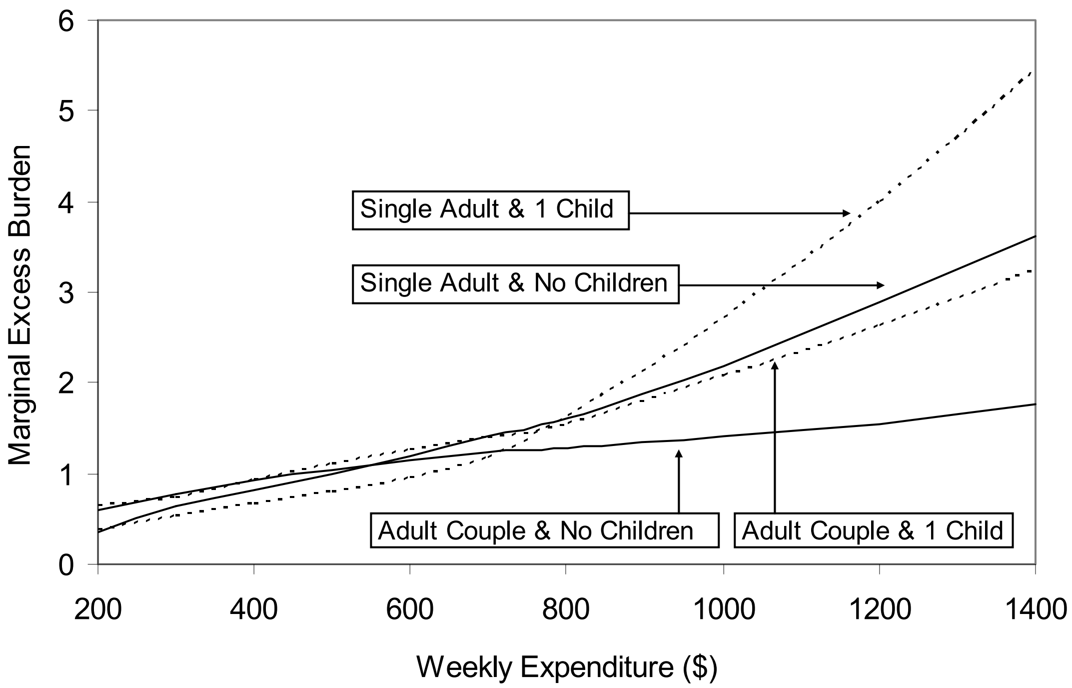


Figure 5 – Marginal Excess Burdens: Single versus Multi-Adult Households

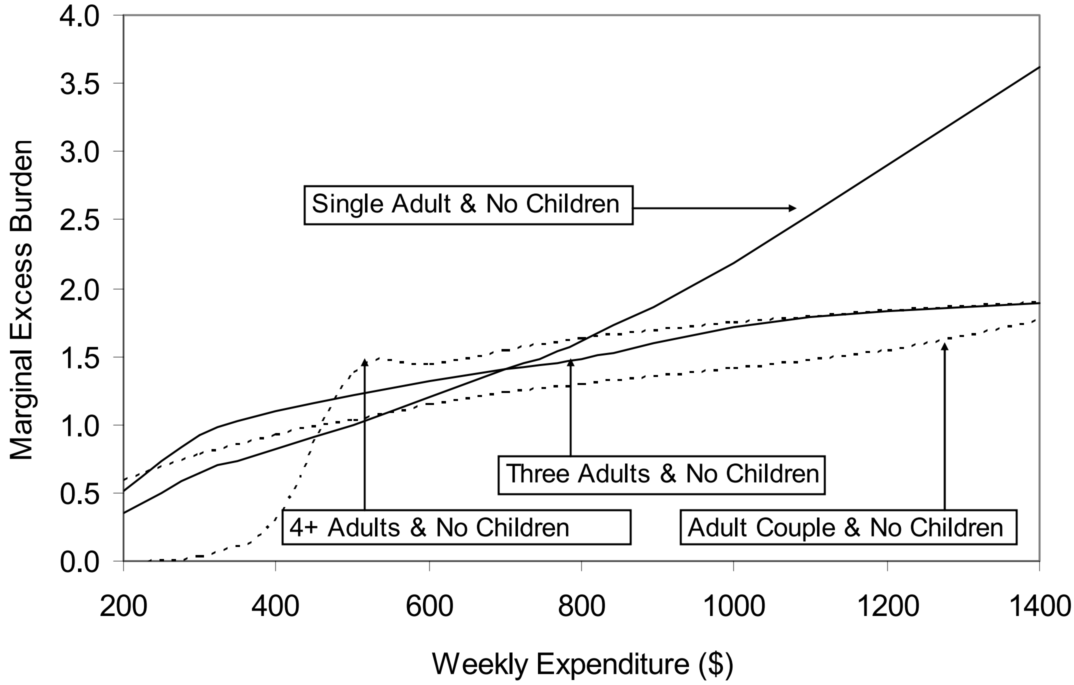
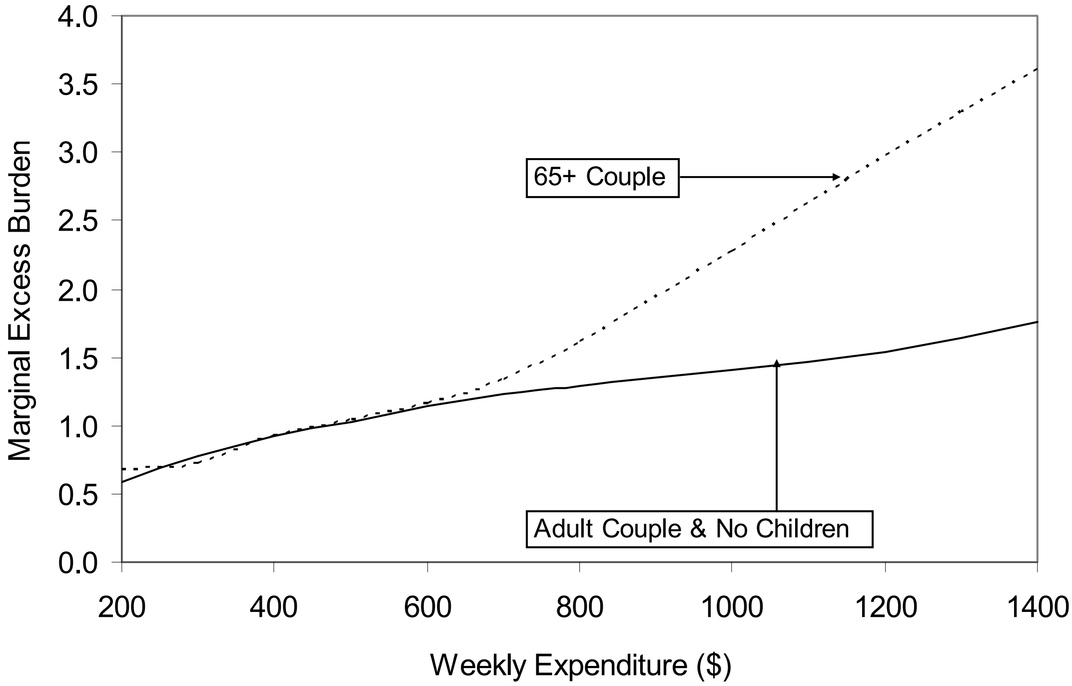


Figure 6 – Marginal Excess Burdens: The Presence of a 65+ Adult



The welfare measures in Tables 5 and 6 were based on three levels of total weekly expenditure. These expenditure levels were chosen for illustrative purposes. Within each household type, there is considerable variation. Table 7 reports the welfare changes at arithmetic mean weekly total expenditure levels for each household type (shown in Table 2), for the case of a $25 carbon tax. The welfare loss is about 1.3 percent for the $25 carbon tax, while the marginal welfare cost varies between approximately 15 and 18 cents for smoking households and 13 and 15 cents for non-smoking households per dollar of additional tax revenue.

Table 7 – Welfare Changes using Mean Expenditures for the $25 Carbon Tax

Household Type	Smokers Mean Total Expenditure	EV	EV / y	ΔT	Non-Smokers Mean Total Expenditure	EV	EV / y	ΔT
1	267	3.14	0.0128	2.86	274	3.65	0.0133	3.22
2	498	6.71	0.0135	5.67	540	7.21	0.0133	6.34
3	406	5.15	0.0127	4.32	437	5.58	0.0128	4.91
4	400	4.89	0.0122	4.23	403	5.12	0.0127	4.50
5	428	5.38	0.0126	4.58	438	5.41	0.0123	4.73
6	468	5.66	0.0121	4.83	475	5.76	0.0121	4.97
7	501	6.11	0.0122	5.02	539	6.49	0.0120	5.86
8	690	8.87	0.0129	7.66	766	9.92	0.0130	8.77
9	668	8.78	0.0131	7.43	763	9.92	0.0130	8.67
10	707	8.96	0.0127	7.83	896	11.29	0.0128	10.10
11	805	10.39	0.0129	9.04	844	10.66	0.0126	9.42
12	673	9.34	0.0139	7.95	822	10.51	0.0128	9.05
13	975	12.40	0.0127	10.69	992	12.90	0.0130	11.42
14	898	11.61	0.0129	10.03	1038	13.41	0.0129	11.83
15	826	11.50	0.0139	9.42	920	12.35	0.0134	10.52
16	1311	16.12	0.0123	14.25	1282	16.03	0.0125	13.96
17	1110	16.36	0.0147	13.83	1129	14.96	0.0133	12.62
18	1070	14.60	0.0136	12.47	925	12.90	0.0140	11.21

4.2 Inequality Measures

The relationship between EV / y and y was used in the previous section to provide a measure of the progressivity, in terms of the disproportionality, of the impact of the carbon tax. However, this indicator does not reflect information concerning the distribution of changes, involving the numbers of households at the various total expenditure levels. Furthermore, this measure only allows comparisons between households in the same demographic group. This section derives a measure of the redistributive effect of the carbon tax which as a summary measure permits comparisons across different demographic groups.

The redistributive effect of the tax change can be examined using the distribution of money metric utility, y_e, before and after the imposition of the carbon tax. A suitable money metric is defined as the value of total expenditure, y_e, which, at some reference set of prices, p_r, would give the same utility as the actual total expenditure.[13] For present purposes, the pre-change prices are used as the reference prices.

An important feature of the inequality measures reported here is that they refer to the inequality of individual (money metric) utilities. Each individual in a household is given that household's value of 'wellbeing', $z = y_e/h,$ where h is the adult equivalent size. The inequality measure reported is the Atkinson measure, A, which is based on the additive welfare function:[14]

$$W = \frac{1}{\sum_{i=1}^{n} p_i} \sum_{i=1}^{N} p_i V\left(z_i\right) \tag{15}$$

where p_i is the number of individuals in the i^{th} household ($i = 1,...,n$) and $V\left(z\right)$ is increasing and concave.[15] Inequality is defined as the proportional difference between the equally-distributed-equivalent, $\tilde{z}$, and the arithmetic mean, $\bar{z}$. Hence, $\tilde{z}$ is the money measure per equivalent adult which, if received by every person, produces the same social welfare as the actual distribution, and:

$$A = 1 - \frac{\tilde{z}}{\bar{z}} \tag{16}$$

Although this may be used with any form of V, the most common form is:

$$V\left(z\right) = \frac{z^{1-\varepsilon}}{1-\varepsilon} \tag{17}$$

where $\varepsilon \neq 1$ is the degree of constant relative inequality aversion of a disinterested judge. For $\varepsilon = 1$, the expression in (17) becomes $V\left(z\right) = \log z$. Thus:

$$\tilde{z} = \frac{1}{\sum_{i=1}^{n} p_i} \left\{ \sum_{i=1}^{n} p_i z^{1-\varepsilon} \right\}^{1/(1-\varepsilon)} \tag{18}$$

[13] It is defined more precisely in Appendix B. Such a measure was used by Fortin and Truchan (1993) with the linear expenditure system (LES) and an early brief discussion of this money metric, also using the LES, was provided by Roberts (1980).

[14] Extended Gini measures of inequality were also produced, but are not reported here as they show similar results

[15] Hence for computing the inequality measure, the household distribution is treated as being weighted, with each household given a frequency corresponding to the total number of people in the household.

The coefficient $\varepsilon \neq 1$ is a measure of relative inequality aversion which, as the degree of concavity of $x^{1-\varepsilon}/(1-\varepsilon)$, reflects the judge's view of the 'wastefulness' of inequality. The value of ε is often linked to a judge's tolerance of the loss involved (using a 'leaky bucket') in making a transfer from a richer to a poorer individual.[16] Adult equivalence scales are based on the following function:

$$h = (n_a + \theta n_c)^{\gamma} \tag{19}$$

where n_a and n_c respectively are the number of adults and children in the household. The parameter θ measures the size of children relative to adults, and the term γ reflects economies of scale in consumption.[17] On the use of this form, see Jenkins and Cowell (1994, p.894). The results reported here use the values $\theta = 0.65$ and $\gamma = 0.75$. These values were found to be approximately the median of a large range of scales used in the literature. For a detailed sensitivity analysis of inequality measures to the choice of the adult equivalence scale see Creedy and Sleeman (2004). A comparison with these results suggests that inequality rises with θ. Profiles of inequality for variations in γ are found to be U-shaped and the value of 0.75 corresponds roughly to the minimum inequality measure, for a given value of θ.

Tables 8, 9, and 10 give the pre and post-carbon tax Atkinson measure of inequality for each of the 18 household groups for both smoking and non-smoking households. Although a range of values of ε were used, the results are reported for the relative inequality aversion coefficient of 1.2, which represents substantial aversion to inequality. Despite this, the percentage increases in inequality were small. Indeed some falls in inequality were recorded. For the top carbon tax rate of $25, the overall redistributive effect of the tax was an increase of just 0.345 percent. This overall effect also reflects the relative numbers of households in the various demographic groups, as well as the distribution of total expenditure among households. By lowering the aversion to inequality or by focussing attention on the lower tax rates, the overall effect of the carbon tax becomes trivial.

[16] For individuals i and j ,with $x_j > x_i$, then $\left.\frac{dx_i}{dx_j}\right|_W = -\left(\frac{x_j}{x_i}\right)^{\varepsilon}$. Hence, if j has twice the income of i, a value of $\varepsilon = 1$ means that the judge is prepared to take $1 from j and transfer only 50 cents to i losing the remaining 50 cents. For survey results on attitudes to inequality, producing values of ε substantially below 1 see Amiel et al (1999).

[17] The use of such scales only affects the inequality calculations for those household types (7, 12 and 15-18) which do not contain a homogenous number of adults and children. Their main use is in producing overall inequality measures.

Table 8 – Inequality Measures for the Carbon Tax of $7 per tonne of Carbon Dioxide

No.	Household Type	Inequality Measure					
		Smoking			Non-Smoking		
		Pre-	Post-	%□	Pre-	Post-	%□
1	65+ Single	0.1567	0.1568	0.0638	0.1695	0.1697	0.1180
2	65+ Couple	0.1044	0.1045	0.0958	0.1733	0.1734	0.0577
3	Single - no children	0.1804	0.1805	0.0277	0.1928	0.1930	0.1037
4	Single - 1 child	0.0876	0.0877	0.1142	0.1310	0.1312	0.1527
5	Single - 2 children	0.1027	0.1028	0.0974	0.1318	0.1318	0.0000
6	Single - 3 children	0.1140	0.1141	0.0877	0.1270	0.1269	-0.0787
7	Single - 4+ children	0.0722	0.0722	0.0000	0.1162	0.1163	0.0861
8	Couple - no children	0.1285	0.1286	0.0778	0.1670	0.1672	0.1198
9	Couple - 1 child	0.1237	0.1237	0.0000	0.1658	0.1660	0.1206
10	Couple - 2 children	0.1072	0.1073	0.0933	0.1749	0.1751	0.1144
11	Couple - 3 children	0.1656	0.1659	0.1812	0.1463	0.1465	0.1367
12	Couple - 4+ children	0.1236	0.1237	0.0809	0.1411	0.1412	0.0709
13	3 adults - no children	0.1354	0.1355	0.0739	0.1387	0.1388	0.0721
14	3 adults - 1 child	0.1284	0.1286	0.1558	0.1387	0.1389	0.1442
15	3 adults - 2+ children	0.1269	0.1270	0.0788	0.1474	0.1475	0.0678
16	4+ adults - no children	0.1120	0.1122	0.1786	0.1122	0.1123	0.0891
17	4+ adults - 1 child	0.1120	0.1121	0.0893	0.2092	0.2094	0.0956
18	4+ adults - 2+ children	0.1675	0.1677	0.1194	0.1748	0.1751	0.1716
	All individuals	Pre: 0.1739		Post: 0.1740		%□ □0.0575	

Table 9 – Inequality Measures for the Carbon Tax of $15 per tonne of Carbon Dioxide

No.	Household Type	Inequality Measure					
		Smoking			Non-Smoking		
		Pre-	Post-	%□	Pre-	Post-	%□
1	65+ Single	0.1567	0.1570	0.1914	0.1695	0.1699	0.2360
2	65+ Couple	0.1044	0.1045	0.0958	0.1733	0.1736	0.1731
3	Single - no children	0.1804	0.1805	0.0554	0.1928	0.1933	0.2593
4	Single - 1 child	0.0876	0.0878	0.2283	0.1310	0.1313	0.2290
5	Single - 2 children	0.1027	0.1028	0.0974	0.1318	0.1317	-0.0759
6	Single - 3 children	0.1140	0.1141	0.0877	0.1270	0.1268	-0.1575
7	Single - 4+ children	0.0722	0.0722	0.0000	0.1162	0.1164	0.1721
8	Couple - no children	0.1285	0.1288	0.2335	0.1670	0.1674	0.2395
9	Couple - 1 child	0.1237	0.1238	0.0808	0.1658	0.1662	0.2413
10	Couple - 2 children	0.1072	0.1074	0.1866	0.1749	0.1754	0.2859
11	Couple - 3 children	0.1656	0.1662	0.3623	0.1463	0.1467	0.2734
12	Couple - 4+ children	0.1236	0.1239	0.2427	0.1411	0.1414	0.2126
13	3 adults - no children	0.1354	0.1357	0.2216	0.1387	0.1390	0.2163
14	3 adults - 1 child	0.1284	0.1288	0.3115	0.1387	0.1392	0.3605
15	3 adults - 2+ children	0.1269	0.1270	0.0788	0.1474	0.1477	0.2035
16	4+ adults - no children	0.1120	0.1124	0.3571	0.1122	0.1125	0.2674
17	4+ adults - 1 child	0.1120	0.1123	0.2679	0.2092	0.2097	0.2390
18	4+ adults - 2+ children	0.1675	0.1678	0.1791	0.1748	0.1755	0.4005
	All individuals	Pre: 0.1739		Post: 0.1742		%□ □0.1725	

Table 10 – Inequality Measures for the Carbon Tax of $25 per tonne of Carbon Dioxide

No.	Household Type	Inequality Measure					
		Smoking			Non-Smoking		
		Pre-	Post-	%□	Pre-	Post-	%□
1	65+ Single	0.1567	0.1572	0.3191	0.1695	0.1701	0.3540
2	65+ Couple	0.1044	0.1047	0.2874	0.1733	0.1739	0.3462
3	Single - no children	0.1804	0.1806	0.1109	0.1928	0.1936	0.4149
4	Single - 1 child	0.0876	0.0879	0.3425	0.1310	0.1315	0.3817
5	Single - 2 children	0.1027	0.1029	0.1947	0.1318	0.1317	-0.0759
6	Single - 3 children	0.1140	0.1142	0.1754	0.1270	0.1267	-0.2362
7	Single - 4+ children	0.0722	0.0721	-0.1385	0.1162	0.1166	0.3442
8	Couple - no children	0.1285	0.1290	0.3891	0.1670	0.1677	0.4192
9	Couple - 1 child	0.1237	0.1239	0.1617	0.1658	0.1665	0.4222
10	Couple - 2 children	0.1072	0.1076	0.3731	0.1749	0.1757	0.4574
11	Couple - 3 children	0.1656	0.1666	0.6039	0.1463	0.1470	0.4785
12	Couple - 4+ children	0.1236	0.1241	0.4045	0.1411	0.1416	0.3544
13	3 adults - no children	0.1354	0.1359	0.3693	0.1387	0.1393	0.4326
14	3 adults - 1 child	0.1284	0.1291	0.5452	0.1387	0.1396	0.6489
15	3 adults - 2+ children	0.1269	0.1270	0.0788	0.1474	0.1479	0.3392
16	4+ adults - no children	0.1120	0.1126	0.5357	0.1122	0.1127	0.4456
17	4+ adults - 1 child	0.1120	0.1124	0.3571	0.2092	0.2100	0.3824
18	4+ adults - 2+ children	0.1675	0.1680	0.2985	0.1748	0.1759	0.6293
	All individuals	Pre: 0.1739		Post: 0.1745		%□ □0.3450	

5 Conclusions

This paper has analysed the potential effects on consumer prices in New Zealand arising from the imposition of three carbon tax rates, namely $7, $15 and $25 per tonne of carbon dioxide. The resulting effects of those price changes on the welfare of a range of household types and total expenditure levels were examined. Finally, the effects on a summary measure of inequality, within each demographic group and over all groups combined, were reported. The price changes were computed using information about inter-industry transactions and the welfare effects were examined using data from pooled Household Economic Surveys. The linear expenditure system was used to model the demand responses of consumers, from which the welfare and inequality effects were calculated.

Households with relatively low total expenditure were found to spend a proportionately greater amount of their income on carbon intensive commodities such as petrol and domestic fuel and power. Despite this, the distributional effect of the carbon tax was not unambiguous, in view of the substantial price increases for several commodity groups on which households with relatively higher total expenditure spend proportionately more.

The ambiguity of the distributional effect of the carbon tax was confirmed by the welfare measures which show that for the majority of households types, the relative burden of the carbon tax (the equivalent variation divided by total expenditure) does not vary monotonically with total expenditure; over some ranges it is regressive while for other ranges of total expenditure it was progressive.

The marginal excess burdens arising from the carbon tax were generally small. However, for three groups, the burdens rose relatively more quickly with expenditure, beyond total expenditure levels of approximately $600 per week. These groups were households with one child relative to households with no children, single adult households relative to multi-adult households and households where the head of a couple was aged over 65 relative to couples where both were aged under 65.

Inequality measures were obtained for a range of degrees of aversion to inequality. Even for very high aversion, the top carbon tax rate of $25 was found to give rise to a very small redistributive effect.

The marginal welfare cost of the carbon tax was found to lie between 18 and 25 cents per dollar of additional tax revenue for all three carbon tax rates.

Appendix A: The Data

Appendix Table 1 – Translation Between the Energy Account Industry Classification (EAIC) and the 49 Industry Group Classification (IGC)

EAIC Code	EAIC Description	IGC Code	IGC Description
A01	Agriculture	1	Horticulture and fruit growing
		2	Livestock and cropping farming
		3	Dairy cattle farming
		4	Other farming
		5	Services to agriculture, hunting and trapping
A02	Fishing and Hunting	5	Services to agriculture, hunting and trapping
		7	Fishing
A03	Forestry and Logging	6	Forestry and logging
A04	Extraction, Mining, Quarrying and Exploration - including gas distribution and supply	8	Mining and quarrying
		9	Oil and gas exploration and extraction
		27	Gas Supply
B01	Petroleum Product Refining, Distribution and Supply	18	Petroleum and industrial chemical manufacturing
B02	Electricity Generation, Distribution and Supply	26	Electricity generation and supply
C01	Slaughtering and Meat Processing	10	Meat and meat product manufacturing
C02	Dairy Products	11	Dairy product manufacturing
C03	Beverages, Tobacco, confectionery and sugar, and other food	12	Other food manufacturing
		13	Beverage, malt and tobacco manufacturing
C04	Textile, Apparel and Leather goods	14	Textile and apparel manufacturing
C05	Wood Processing and Wood Products	15	Wood product manufacturing
C06	Paper and Paper Products, Printing and Publishing	16	Paper and paper product manufacturing
		17	Printing, publishing and recorded media
C07	Chemicals, Related Products and Plastics	19	Rubber, plastic and other chemical product manufacturing
C08	Concrete, Clay, Glass and Related Minerals Manufacture	20	Non-metallic mineral product manufacturing
C09	Basic Metal Industries	21	Basic metal manufacturing
C10	Fabricated Metal Products, Machinery and Equipment	22	Structural, sheet and fabricated metal product manufacturing
		23	Transport equipment manufacturing
		24	Machinery and equipment manufacturing
C11	Other Manufacturing Industries	25	Furniture and other manufacturing
C12	Construction	29	Construction
D01	Water Works and Supply	28	Water supply
D02	Wholesale and Retail Trade - Non Food	30	Wholesale trade
		31	Retail trade

EAIC Code	EAIC Description	IGC Code	IGC Description
D03	Wholesale Trade - Food	30	Wholesale trade
D04	Retail Trade - Food	31	Retail trade
D05	Motels, Hotels, Guest Houses	32	Accommodation, restaurants and bars
D06	Communication	36	Communication services
D07	Finance, Insurance, Real Estate and Business Services	37	Finance
		38	Insurance
		39	Services to finance and insurance
		40	Real estate
		41	Ownership of owner-occupied dwellings
		42	Equipment hire and investors in other property
		43	Business services
D08	Central Government Administration	44	Central government administration, defence, public order and safety services
D09	Central Government Defence Services	44	Central government administration, defence, public order and safety services
D10	Local Government Administration	45	Local government administration services and civil defence
D11	Education Services: Pre-School, Primary and Secondary	46	Education
D12	Education Services: Tertiary Education	46	Education
D13	Health and Welfare Services	47	Health and community services
D14	Other Social and Related Community Services	48	Cultural and recreational services
		49	Personal and other community services
D15	Sanitary and Cleaning Services	45	Local government administration services and civil defence
E01	Domestic Transport and Storage	33	Road transport
		34	Water and rail transport
		35	Air transport, services to transport and storage

Statistics New Zealand provided fuel demands based on the EAIC. The above translation was used to convert the fuel demands to the 49 industry group classification. Where an industry from the EAIC incorporated multiple IGC industries, final demand was used as a weight to distribute the fuel demand of the EAIC industry to each of the IGC industries.

Appendix Table 2 – Fuel Demands by Industry Group Classification (IGC) for the Year Ended March 1996 (Gross PJ)

IGC Code	Coal	Lignite	Crude Petroleum	Natural Gas	LPG	Petrol	Diesel	Fuel Oil	Aviation Fuels & Kerosene
1	0.000	0.000	0.000	0.017	0.000	5.029	9.032	0.014	0.070
2	0.000	0.000	0.000	0.004	0.000	1.197	2.149	0.003	0.017
3	0.000	0.000	0.000	0.004	0.000	1.200	2.156	0.003	0.017
4	0.000	0.000	0.000	0.003	0.000	0.909	1.632	0.003	0.013
5	0.000	0.000	0.000	0.466	0.000	0.631	4.029	0.374	0.009
6	0.000	0.000	0.000	0.000	0.000	0.635	1.564	0.000	0.000
7	0.000	0.000	0.000	0.723	0.000	0.008	4.525	0.580	0.000
8	0.454	0.000	0.000	0.012	0.000	0.171	1.333	0.179	0.000
9	0.284	0.000	0.000	0.007	0.000	0.107	0.832	0.112	0.000
10	2.273	0.318	0.000	1.184	0.412	0.403	0.099	0.138	0.000
11	5.784	0.808	0.000	4.455	0.045	0.001	1.524	0.457	0.000
12	0.537	0.075	0.000	2.602	0.504	1.434	0.925	0.715	0.000
13	0.187	0.026	0.000	0.905	0.175	0.498	0.321	0.248	0.000
14	0.557	0.078	0.000	0.962	0.047	0.140	0.504	0.383	0.000
15	0.310	0.043	0.000	0.936	0.043	0.008	0.149	0.677	0.000
16	0.572	0.080	0.000	2.649	0.150	0.006	0.083	1.310	0.000
17	0.251	0.035	0.000	1.160	0.066	0.002	0.036	0.573	0.000
18	0.000	0.000	152.267	0.000	0.000	0.000	0.000	0.000	0.000
19	0.279	0.039	0.000	86.372	0.193	0.116	2.467	0.566	0.000
20	4.272	0.597	0.000	1.134	0.645	0.000	0.346	0.094	0.000
21	13.862	0.000	0.000	7.955	0.392	0.007	0.160	2.191	0.000
22	0.017	0.002	0.000	0.136	0.078	0.048	0.454	0.044	0.000
23	0.036	0.005	0.000	0.292	0.168	0.103	0.972	0.094	0.000
24	0.061	0.009	0.000	0.503	0.289	0.177	1.674	0.163	0.000
25	0.092	0.013	0.000	0.167	0.012	0.104	0.016	0.002	0.000
26	5.290	0.000	0.000	51.118	0.000	0.068	0.134	0.000	0.000
27	0.233	0.000	0.000	0.006	0.000	0.088	0.683	0.092	0.000
28	0.000	0.000	0.000	0.000	0.000	0.023	0.051	0.000	0.000
29	0.000	0.000	0.000	0.111	0.594	1.946	7.201	0.000	0.192
30	0.789	0.043	0.000	0.374	0.331	9.764	0.779	0.028	0.000
31	0.923	0.050	0.000	1.043	0.366	11.228	0.810	0.030	0.000
32	0.033	0.002	0.000	0.934	0.355	0.704	0.159	0.541	0.000
33	0.009	0.000	0.000	0.194	0.000	1.083	2.199	0.318	3.579
34	0.013	0.000	0.000	0.295	0.000	1.647	3.345	0.484	5.443
35	0.056	0.000	0.000	1.274	0.000	7.126	14.473	2.092	23.551
36	0.000	0.000	0.000	0.038	0.018	0.827	0.562	0.000	0.000
37	0.008	0.000	0.000	0.056	0.000	0.150	0.000	0.045	0.000
38	0.008	0.000	0.000	0.058	0.000	0.153	0.000	0.046	0.000
39	0.000	0.000	0.000	0.002	0.000	0.006	0.000	0.002	0.000
40	0.020	0.001	0.000	0.146	0.000	0.388	0.000	0.117	0.000
41	0.056	0.003	0.000	0.415	0.000	1.104	0.000	0.333	0.000
42	0.002	0.000	0.000	0.012	0.000	0.032	0.000	0.010	0.000
43	0.010	0.001	0.000	0.074	0.000	0.198	0.000	0.060	0.000
44	0.530	0.029	0.000	0.299	0.000	0.643	1.902	2.194	1.918
45	0.034	0.002	0.000	0.332	0.000	0.921	0.425	0.014	0.000
46	1.240	0.067	0.000	0.518	0.000	0.000	0.000	0.144	0.000

IGC Code	Coal	Lignite	Crude Petroleum	Natural Gas	LPG	Petrol	Diesel	Fuel Oil	Aviation Fuels & Kerosene
47	3.156	0.170	0.000	0.976	0.000	0.835	0.000	0.000	0.000
48	0.051	0.003	0.000	0.036	0.000	0.636	0.000	0.056	0.000
49	0.029	0.002	0.000	0.020	0.000	0.359	0.000	0.032	0.000

Appendix Table 3 – Carbon Dioxide Intensities by Industry Group Classification (IGC) for the Year Ended March 1996

IGC No.	IGC Description	CO2 (tonnes) per Dollar of Output	IGC No.	IGC Description	CO2 (tonnes) per Dollar of Output
1	Horticulture and fruit growing	0.96	26	Electricity generation and supply	1.21
2	Livestock and cropping farming	0.40	27	Gas supply	0.36
3	Dairy cattle farming	0.40	28	Water supply	0.26
4	Other farming	0.58	29	Construction	0.32
5	Services to agriculture, hunting and trapping	0.68	30	Wholesale trade	0.24
6	Forestry and logging	0.34	31	Retail trade	0.24
7	Fishing	0.68	32	Accommodation, restaurants and bars	0.26
8	Mining and quarrying	0.41	33	Road transport	0.35
9	Oil & gas exploration & extraction	0.23	34	Water and rail transport	0.70
10	Meat and meat product manufacturing	0.41	35	Air transport, services to transport and storage	0.86
11	Dairy product manufacturing	0.58	36	Communication services	0.07
12	Other food manufacturing	0.43	37	Finance	0.05
13	Beverage, malt and tobacco manufacturing	0.31	38	Insurance	0.06
14	Textile and apparel manufacturing	0.25	39	Services to finance and insurance	0.06
15	Wood product manufacturing	0.39	40	Real estate	0.06
16	Paper & paper product manufacturing	0.40	41	Ownership of owner-occupied dwellings	0.07
17	Printing, publishing & recorded media	0.28	42	Equipment hire and investors in other property	0.12
18	Petroleum and industrial chemical manufacturing	3.64	43	Business services	0.10
19	Rubber, plastic and other chemical product manufacturing	1.83	44	Central government administration, defence, public order and safety services	0.19
20	Non-metallic mineral product manufacturing	0.66	45	Local Government Administration Services and Civil Defence	0.17
21	Basic metal manufacturing	1.40	46	Education	0.10
22	Structural, sheet and fabricated metal product manufacturing	0.37	47	Health and community services	0.15
23	Transport equipment manufacturing	0.23	48	Cultural and recreational services	0.11
24	Machinery & equipment manufacturing	0.29	49	Personal and other community services	0.14
25	Furniture and other manufacturing	0.29			

Appendix Table 4 – Translation Between the 22 HES Group Classification and the 49 Industry Group Classification

	22 HES Group Classification		49 Industry Group Classification (IGC)
1	Food	1	Horticulture and fruit growing
		2	Livestock and cropping farming
		3	Dairy cattle farming
		4	Other farming
		5	Services to agriculture, hunting and trapping
		7	Fishing
		10	Meat and meat product manufacturing
		11	Dairy product manufacturing
		12	Other food manufacturing
2	Food outside home	1	Horticulture and fruit growing
		2	Livestock and cropping farming
		3	Dairy cattle farming
		4	Other farming
		5	Services to agriculture, hunting and trapping
		7	Fishing
		10	Meat and meat product manufacturing
		11	Dairy product manufacturing
		12	Other food manufacturing
		32	Accommodation, restaurants and bars
3	Rent	32	Accommodation, restaurants and bars
		40	Real estate
4	Pay to Local Authorities	28	Water Supply
		45	Local Govt. Admin Services and Civil Defence
5	House maintenance	8	Mining and Quarrying
		15	Wood product manufacturing
		20	Non-metallic mineral product manufacturing
		29	Construction
		41	Ownership of owner-occupied dwellings
6	Domestic fuel and power	26	Electricity generation and supply
		27	Gas supply
7	Household equipment	16	Paper and paper product manufacturing
		17	Printing, publishing and recorded media
		19	Rubber, plastic & other chemical product manufacturing
			Machinery and Equipment manufacturing
		24	Wholesale trade
		30	Retail trade
		31	Equipment hire and investors in other property
		42	
	22-Group HES Classification		49 Industry Group Classification (IGC)
8	Furnishings	25	Furniture and other manufacturing
9	Household services	19	Rubber, plastic and other chemical product manufacturing
10	Adult clothing	14	Textile and apparel manufacturing
11	Children's clothing	14	Textile and apparel manufacturing
12	Public transport in NZ	33	Road transport
		34	Water and rail transport
13	Overseas travel	35	Air transport, services to transport and storage
14	Vehicle purchase	23	Transport equipment manufacturing
15	Petrol etc	9	Oil and gas exploration and extraction
		18	Petroleum and industrial chemical manufacturing

	22 HES Group Classification		49 Industry Group Classification (IGC)
16	Vehicle supplies, parts etc	23	Transport equipment manufacturing
17	Cigarettes and tobacco	13	Beverage, malt and tobacco manufacturing
18	Alcohol	13	Beverage, malt and tobacco manufacturing
		32	Accommodation, restaurants and bars
19	Medical, cosmetics etc	47	Health and community services
20	Services	36	Communication services
		37	Finance
		38	Insurance
		39	Services to finance and insurance
		44	Central govt admin, defence public order, etc
		46	Education
		47	Health and community services
		48	Cultural and recreational services
		49	Personal and other community services
21	Recreational vehicles	23	Transport equipment manufacturing
22	Other expenditure	-	An average of all included industries
-	Industries Excluded	6	Forestry and Logging
		21	Basic metal manufacturing
		22	Structural, sheet and fabricated metal product manufacturing
			Business services
		43	

Placements were made by locating the commodity group which contained the output of the industry concerned.

Appendix B: Welfare Changes and Demand Elasticities

This appendix describes the computation of the welfare measures and the method used to compute the required parameters for each demographic group and total expenditure level. Only the main results are stated, as their derivations are available elsewhere.[18] The basis of the approach is the use of the linear expenditure system to model households' behaviour. The total expenditure of each household is assumed to remain fixed when prices of goods and services change. Thus, possible changes in production (associated with the changing structure of demands) and factor prices, along with the distribution of income, are ignored.

The direct utility function for the linear expenditure system is:

$$U = \prod_{i=1}^{n} \left(x_i - \gamma_i\right)^{\beta_i} \tag{B1}$$

with $0 \leq \beta_i \leq 1$, and $\sum_{i=1}^{n} \beta_i = 1$. Here, x_i and γ_i are respectively the total and the committed consumption of good i. If p_i is the price of good i, and y is total household expenditure, the budget constraint is $\sum_{i=1}^{n} p_i x_i = y$. In the present context, the parameters of the utility function differ according to both household type and total expenditure, as discussed further below. The next two subsections define equivalent variations and money metric utility, which are used in the distributional analyses.

Equivalent Variations

The equivalent variation, EV, is defined in terms of the expenditure function as $EV = E\left(p_1, U_1\right) - E\left(p_0, U_1\right)$, where $E\left(p, U\right)$ is the minimum expenditure required to reach utility level U at prices p. Defining the terms A and B respectively as $\sum_{i=1}^{n} p_i \gamma_i$ and $\prod_{i=1}^{n} \left(p_i / \beta_i\right)^{\beta_i}$, the indirect utility function, $V(p, y)$, is:

$$V = \left(y - A\right)/B \tag{B2}$$

The expenditure function is found by inverting this and substituting E for y to get:

$$E\left(p, U\right) = A + BU \tag{B3}$$

Suppose that the vector of prices changes from p_0 to p_1. Substituting for E using (B3) and assuming that total expenditure remains constant at y, gives:

[18] For example, see Powell (1974), Allen (1975), Creedy (1998a,b).

$$EV = y - (A_0 + B_0 U_1) \quad \text{(B4)}$$

Substituting for U_1, using equation (B2), into (B4) gives:

$$EV = y - A_0 \left[1 + \frac{B_0}{B_1} \left(\frac{y}{A_0} - \frac{A_1}{A_0} \right) \right] \quad \text{(B5)}$$

The term A_1/A_0 is a Laspeyres type of price index, using γ_i s as weights. The term B_1/B_0 simplifies to $\prod_{i=1}^{n} \left(p_{1i}/p_{0i} \right)^{\beta_i}$, which is a weighted geometric mean of price relatives.[19] A convenient feature of the present approach is that the expression for the equivalent variation requires only the percentage changes in prices to be specified.

Money Metric Utility

For distributional analyses of tax reforms, it is necessary to have a money metric measure of each household's utility. A suitable money metric is defined as the value of total expenditure, y_e, which, at some reference set of prices, p_r, would give the same utility as the actual total expenditure.[20] A feature of this metric is that it ensures that alternative situations are evaluated using a common set of reference prices. It is, importantly, invariant with respect to monotonic transformations of utility. Using the expenditure function gives:

$$y_e = E\left(p_r, V(p, y) \right) \quad \text{(B6)}$$

For the linear expenditure system, this is found to be:

$$y_e = \sum_{i=1}^{n} p_{ri}\gamma_i + \left\{ \prod_{i=1}^{n} \left(\frac{p_{ri}}{p_i} \right)^{\beta_i} \right\} \left\{ y - \sum_{i=1}^{n} p_i \gamma_i \right\} \quad \text{(B7)}$$

The effect on welfare can be measured in terms of a change in y_e from y_{e0} to y_{e1}, where, as before, the indices 0 and 1 refer to pre- and post-change values respectively. If pre-change prices are used as reference prices, so that $p_{ri} = p_{0i}$ for all i, y_{e1} is simply the value of actual total expenditure after the change less the value of the equivalent variation; that is, $y_{e1} = y_1 - EV$. Hence the proportionate change, $(y_1 - y_{e1})/y_1$, is conveniently the ratio of EV to y_1.

Total Expenditure Elasticities

Given cross-sectional budget data, the total expenditure elasticities, for different household types, can be obtained by first estimating the relationship, for each commodity group, between the budget shares and total household expenditure. If

[19] The corresponding result for the compensating variation follows by substituting into $CV = E(p_1, U_0) - E(p_0, U_0)$.

[20] In terms of the indirect utility function, y_e is defined by $V(p_r, y_e) = V(p, y)$ This metric was called 'equivalent income' by King (1983), but this term can lead to confusion when used in conjunction with adult equivalent scales.

$w_i = p_i x_i / \sum_{i=1}^{n} p_i x_i = p_i x_i / y$ is the budget share of the i^{th} good, a flexible specification that has been found to provide a good fit is (omitting subscripts):[21]

$$w = \delta_1 + \delta_2 \log y + \frac{\delta_3}{y} \quad \text{(B8)}$$

This form has the convenient property that, if parameters are estimated using ordinary least squares, the adding-up condition, $\sum_{i=1}^{n} w_i = 1,$ holds for predicted shares, at all total expenditure levels, y. With the level of disaggregation used, it was necessary to carry out a total of 792 ($22 \times 2 \times 18$) budget share regressions. Hence these cannot be reported here.

At any given level of $y,$ the expenditure elasticity is given by:

$$e = 1 + \frac{dw}{dy}\frac{y}{w} \quad \text{(B9)}$$

which can be expressed as:

$$e = 1 + \frac{(y/\delta_3)\delta_2 - 1}{(y/\delta_3)(\delta_1 + \delta_2 \log y) + 1} \quad \text{(B10)}$$

so that $e = 0$ for $y = 0,$ and converges to 1 as $y \to \infty$ (though of course it may exceed unity over certain ranges of y).

Demand Elasticities

For the linear expenditure system, the total expenditure elasticities are:

$$e_i = \frac{\beta_i}{w_i} \quad \text{(B11)}$$

Hence, given values of $e_i,$ calculated using (B10), the corresponding value of β_i can easily be obtained using (B11), as $\beta_i = e_i w_i$.

Cross-sectional budget data do not provide direct information about price responses. However, the own-price elasticities, $e_{ii},$ and cross-price elasticities, $e_{ij},$ are obtained using a general property of directly additive utility functions. It was shown by Frisch (1959) that:

$$e_{ij} = -e_i w_j \left(1 + \frac{e_j}{\xi}\right) \quad \text{(B12)}$$

[21] For further discussion of this form, see Deaton and Muellbauer (1980). One small difficulty with its use is that ordinary least squares estimators do not guarantee that predicted budget shares are always non-negative. In the few cases where this arises - for very low y, the w are replaced by zero, and others are adjusted to ensure additivity.

$$e_{ii} = e_i \left\{ \frac{1}{\xi} - w_i \left(1 + \frac{e_i}{\xi} \right) \right\} \tag{B13}$$

In these expressions, ξ denotes the elasticity of the marginal utility of total expenditure with respect to total expenditure; this is called the Frisch parameter.

The computation of welfare changes does not actually require each value of γ_i, but the value of $p_i\gamma_i$, the committed expenditure on good i. Given own-price elasticities of demand for each good at each income level, obtained using (B13), the committed expenditures can be obtained by making use of the property of the linear expenditure system that:

$$e_{ii} = \frac{\gamma_i (1 - \beta_i)}{x_i} - 1 \tag{B14}$$

Hence:

$$p_i\gamma_i = \frac{w_i y (1 + e_{ii})}{1 - \beta_i} \tag{B15}$$

A difficulty is that household budget data cannot provide direct estimates of the Frisch parameter. It is therefore necessary to make use of extraneous information. The results reported above were obtained using a fixed Frisch parameter of -1.9.[22] However, experiments with varying Frisch parameters, allowing the absolute Frisch to fall as total expenditure rises, showed that the results were not sensitive.

Price Changes

In general the demand functions can be expressed as $x_i = x_i \left(p_1, ..., p_n | y \right)$. Holding y constant and differentiating the demand for good i with respect to the prices gives:

$$\dot{x}_i = \sum_{j=1}^{n} e_{ij} \dot{p}_j \tag{B16}$$

where the dots again indicate proportionate changes and e_{ij} is the elasticity of demand for i with respect to a change in the price of good j. The proportional change in the budget share, $\dot{w}_i$, is:

$$\dot{w}_i = \dot{p}_i + \sum_{j=1}^{n} e_{ij} \dot{p}_j \tag{B17}$$

which, as total expenditure is fixed, is equivalent to the proportional change in expenditure on good i.

[22] For a review of earlier estimates of the Frisch parameter, see Brown and Deaton (1973). Tulpule and Powell (1978) used a value of $\xi = -1.82$ when calculating elasticities at average income for Australia, based on work of Williams (1978), and this value was adopted by Dixon et al (1982) in calibrating a general equilibrium model.

A convenient feature of the present approach is that the expression for the equivalent variation requires only the percentage changes in prices to be specified. The relevant terms can be expressed in terms of the $\dot{p}$s. Since $p_{1i} = p_{0i}\left(1+\dot{p}_i\right)$, and defining $s_i = p_{0i}\gamma_i / \sum_i p_{0i}\gamma_i$, it can be shown that $A_1/A_0 = 1 + \sum_i s_i \dot{p}_i$ and $B_1/B_0 = \prod_i \left(1+\dot{p}_i\right)^{\beta_i}$. Suppose that all prices change by the same proportion. If all prices change in the same proportion, $\dot{p}_i = \dot{p}$ for all i, and $B_1/B_0 = A_1/A_0 = 1 + \dot{p}$.

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