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CARBON TAXATION, PRICES AND WELFARE IN NEW ZEALAND

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Carbon Taxation, Prices and Welfare in New Zealand[1]

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Abstract

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

JEL Classification	H23, H31, Q58, D57
Keywords	Carbon tax; equivalent variations; excess burdens; inequality

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1 Introduction

A carbon tax, designed to reduce carbon dioxide emissions, operates by providing an incentive for consumers and firms to substitute away from those goods which have the highest carbon intensities. The prices of the more carbon intensive goods increase proportionately more than those with lower intensities. These intensities in turn depend on the fossil fuels used in the production of each good and the nature of inter-industry transactions. Such a tax is obviously designed to 'correct' a market failure – the absence of a market for carbon dioxide – but it can also have 'unintended consequences'. These include the fact that the price changes induced by the tax may give rise to excess burdens. In addition, there may be adverse impacts on the distribution of welfare. Inequality may increase if the price changes are higher for those goods which form a larger share of the budgets of relatively low-income households. If the welfare of low-income households is more severely affected than the welfare of high-income households, then information about those distributional effects can be used to design compensating changes to the direct tax and transfer system.[3]

The aim of this paper is to investigate the likely orders of magnitude of the welfare and distributional effects of the price changes arising from a carbon tax in New Zealand. The Government is committed to such a tax as part of the policy package on climate change, which is designed to meet New Zealand's greenhouse gas reduction target under the Kyoto Protocol. The proposed charge will approximate international emissions prices, but will be capped at NZ$25 per tonne of carbon dioxide. The majority of carbon tax studies have concentrated on emissions reductions using general equilibrium or macroeconomic models which allow very little disaggregation of the household sector. The approach used here is based on the pioneering work of Proops et al (1993) and Symons et al (1994), but uses the type of demand system and welfare measurement developed by Creedy and Cornwell (1996, 1997).[4] In order to allow for substantial population heterogeneity, the model is necessarily partial equilibrium in nature, in that it makes no

[3] More widely discussed positive effects are associated with the use of carbon tax revenue to reduce other distorting taxes, such as income taxation. On these aspects, see for example Carraro et al (1996), McKitrick (1997) and Smith (1998).

allowance for factor prices changes that may arise from demand and output changes. It also concentrates on consumer demands, making extensive use of cross-sectional household expenditure data. Hence possible changes to inter-industry transactions, reflected in changes in coefficients of the input-output matrix, and producer substitutions between fuels, are ignored here (allowance for such effects in the context of Australia are modelled by Creedy and Martin, 2000).

The analysis proceeds as follows. First, a link is established between the carbon tax (expressed in terms of tonnes of carbon dioxide) and the price changes of commodities; this link depends on the carbon dioxide intensities of each good. Second, it is necessary to evaluate the effects on the welfare of households resulting from the price changes; this stage requires the use of a demand model. This paper uses the linear expenditure system, where the parameters are allowed to vary among household types and total expenditure levels. Third, the overall evaluation of the carbon tax requires the calculation of inequality measures, involving an allowance for differences in household composition.

Section 2 sets out the basic framework of analysis. The expression for the carbon dioxide intensities of commodities is derived in subsection 2.1. 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 provided in subsection 2.2. Section 3 applies the framework to produce the price changes arising from a carbon tax of $25 in New Zealand. It describes the main data sources and reports the effective *ad valorem* tax rates. Section 4 analyses the welfare effects arising from the carbon tax. It begins by describing the treatment of household demands and then examines welfare changes, measured in terms of equivalent variations, for a range of household types and levels of total weekly expenditure. These welfare measures provide an indication of the disproportionality of the impact at different total expenditure levels, for the household types. Overall measures of inequality are reported in section 5, 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 6.

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[4] Other studies concentrating on microeconomic aspects include Nichele and Robin (1995) for France, Labandeira and Labeager (1999) for Spain and Brannlund and Nordstrom (2004) for Sweden.

2 A Carbon Tax and Price Changes

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 terms of physical amounts of carbon into an equivalent tax imposed per dollar of expenditure by final consumers of each good. This is achieved through using the carbon intensity of each good.

As with other studies of carbon taxes, the tax examined is considered to be imposed on carbon dioxide intensity, rather than the 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:[5]

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

As the carbon 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

[5] The tax-exclusive tax rate is simply the ratio of tax paid to the tax-exclusive price of the good. Conversely, the tax-inclusive tax rate is the ratio of tax paid to the tax-inclusive price of the good.

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.

2.1 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 and 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, can 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 this 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. The sum of the series is given by $S = I + A + A^2 + \ldots = (I - A)^{-1}$, 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. The non-negative solution is thus:

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

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

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:

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

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

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

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

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

This expression is used together with a selected carbon tax rate to calculate the effective carbon tax rates given by equation (1). The expression in equation (11) is a simplified form of that obtained by Proops et al (1993) and Symons et al (1994). 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.

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:

$$p_1 = p_0\left(1+t\right) \tag{12}$$

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:

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

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 increase in the price of each good.

3 A Carbon Tax in New Zealand

This section outlines the New Zealand data used to determine the carbon dioxide intensity of each industry and reports the effective tax rates and price changes arising from a $25 carbon dioxide tax rate. The values of final demands are measured in thousands of dollars. Hence a carbon tax of $25 per tonne of carbon dioxide translates into a value of α of 0.025.

3.1 Fuel Use and Carbon Content

Inter-industry flows in value terms were obtained from the "Inter Industry Study of 1996" from New Zealand's *System of National Accounts* for a 49 industry group classification (IGC). This is the most recent year for which the data are available. The flows were divided by each industry's gross output to produce the direct requirement coefficients of 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 provide 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). Hence it was necessary to translate between the Energy Account Industry Classification (EAIC) and the 49 industry group classification (IGC) used for the present analysis. This provided nine fossil fuels for analysis. Dividing these figures by each industry's gross output provided the required elements of the (49×9) F matrix. For details of the translations and data on fossil fuel use, see Creedy and Sleeman (2004).

Data from several sources were used to compile the 9-element e vector of carbon dioxide emissions. Table 1 outlines the carbon dioxide emission factors for each of the nine fossil fuels analysed, along with their sources. 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.

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)

Not surprisingly, petroleum and industrial chemical manufacturing, 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, and basic metal manufacturing, which respectively demand the largest quantities of natural gas and coal, also recorded high carbon contents of

1.83 and 1.40 tonnes of carbon dioxide per dollar of gross output. The only other industry whose carbon content exceeded 1 was electricity generation and supply, with 1.21.

3.2 Taxes and Prices

In modelling the price changes arising from the carbon tax, 22 commodity groups were identified, and it was therefore necessary to provide a translation between the 49 industry group classification and this 22 group classification. For details of the translation see Creedy and Sleeman (2004).

All existing indirect taxes were required to be expressed in terms of tax-exclusive *ad valorem* tax rates. While this was straightforward for most commodity groups, for which only the Goods and Services Tax (GST) applies, the conversion was more complex where an excise tax is also imposed, as these are typically based on units of the commodity rather than values. Table 2 shows the groups used and the effective *ad valorem* tax-exclusive rates, t, expressed as percentages. The rates were taken from Young (2002), which gives details for a more disaggregated set; where several categories were combined, the effective rates were calculated as a weighted average of the individual components. Table 2 indicates the high effective rates on petrol, cigarettes and tobacco and alcohol, which are typically rationalised on merit good and externality grounds.

Table 2 - Commodity Groups and Tax Rates

No.	Commodity Group	100t %	No.	Commodity Group	100t %
1	Overseas Travel	0	12	Household Services	12.5
2	Rent	0	13	Adult’s Clothing	12.5
			14	Children’s Clothing	12.5
3	Recreational Vehicles	6.3	15	Public Transport in NZ	12.5
4	Vehicle Purchases	7.1	16	Vehicle Supplies, Parts, etc	12.5
			17	Medical, Cosmetic etc	12.5
5	Food	12.5	18	Services	12.5
6	Food Outside Home	12.5	19	Other Expenditure	12.5
7	Pay to Local Authorities	12.5			
8	House Maintenance	12.5	20	Alcohol	46.8
9	Domestic Fuel and Power	12.5	21	Petrol	71.8
10	Household Equipment	12.5	22	Cigarettes and Tobacco	239.8
11	Furnishings	12.5			

Table 3 shows the effective carbon tax rates for the 22 commodity groups, τ, and the new effective *ad valorem* tax rates, t^*, expressed as percentages, that result from a carbon tax of $25. Petrol faces by far the greatest price increase. For the majority of household types, low-income earners spend a proportionately greater amount of their budget on petrol than high-income earners. Similarly, domestic fuel and power, and food both face substantial price rises as a result of the carbon tax, and also form relatively higher proportions of the budgets of lower-income earners. These findings suggest that the carbon tax may have a proportionately greater impact on those households with relatively lower levels of total expenditure. However, the effect of the carbon tax is not unambiguous. The price of food consumed outside the home also rises substantially, and in this case higher-income earners spend a proportionately larger amount of their budgets on this good. Overseas travel incurs the fourth largest price increase, and its budget share increases with total expenditure.[6]

Table 3 - Effective Carbon Tax and Effective *Ad Valorem* Tax Rates

No.	Commodity Group	100τ %	$100t^*$ %	No.	Commodity Group	100τ %	$100t^*$ %
1	Overseas Travel	2.16	2.16	12	Household Services	4.59	17.66
2	Rent	0.40	0.40	13	Adult's Clothing	0.63	13.21
				14	Children's Clothing	0.63	13.21
3	Recreational Vehicles	0.56	6.85	15	Public Transport in NZ	1.40	14.08
4	Vehicle Purchases	0.56	7.65	16	Vehicle Supplies, Parts, etc	0.56	13.13
				17	Medical, Cosmetic etc	0.37	12.92
5	Food	1.28	13.94	18	Services	0.32	12.86
6	Food Outside Home	1.17	13.82	19	Other Expenditure	0.85	13.46
7	Pay to Local Authorities	0.43	12.99				
8	House Maintenance	0.52	13.09	20	Alcohol	0.69	47.83
9	Domestic Fuel and Power	2.75	15.59	21	Petrol	7.60	84.83
10	Household Equipment	0.90	13.52	22	Cigarettes and Tobacco	0.77	242.45
11	Furnishings	0.71	13.30				

4 Welfare Changes for Households

This section reports the effects of a carbon tax on the welfare of different household types at different levels of total weekly expenditure. Subsection 4.1 briefly describes the way household demands are modelled and the way welfare changes are computed. Empirical results are provided in subsection 4.2.

4.1 Household Demands

[6] 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.

The basis of the approach is the use of the linear expenditure system to model households' behaviour; for example; see Creedy (1998). The direct utility function is:

$$U = \prod_{i=1}^{n} \left(\omega_i - \gamma_i\right)^{\beta_i} \tag{15}$$

with $0 \le \beta_i \le 1$, and $\sum_{i=1}^{n} \beta_i = 1$. Here, ω_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 m is total weekly household expenditure, the budget constraint is $\sum_{i=1}^{n} p_i \omega_i = m$. In the present context, the parameters of the utility function, γ_i and β_i, differ according to both household type and total expenditure level, m.

The equivalent variation is $EV = E\left(p_1, U_1\right) - E\left(p_0, U_1\right)$, where $E\left(p, U\right)$ is the minimum expenditure required to reach utility 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, $V\left(p, m\right)$, is:

$$V = \frac{m - A}{B} \tag{16}$$

The expenditure function is found by inverting this and substituting E for m to give:

$$E\left(p, U\right) = A + BU \tag{17}$$

Suppose that the vector of prices changes from p_0 to p_1. Substituting for E using equation (17) and holding total expenditure constant:

$$EV = m - \left(A_0 + B_0 U_1\right) \tag{18}$$

Substituting for U_1, using equation (16), into (18) leads equivalent variation to become:

$$EV = m - A_0 \left[1 + \frac{B_0}{B_1}\left(\frac{m}{A_0} - \frac{A_1}{A_0}\right)\right] \tag{19}$$

The term A_1 / A_0 is a Laspeyres type of price index, using γ_is 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. A convenient feature of the present approach is that the expression for the equivalent variation can be rewritten in terms of the percentage changes in prices, thereby avoiding the need to provide actual price levels.

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

$w_i = p_i\omega_i / \sum_{i=1}^{n} p_i\omega_i = p_i\omega_i / m$ is the budget share devoted to the i^{th} good, a flexible specification that has been found to provide a good fit is:

$$w_i = \delta_{1i} + \delta_{2i} \log m + \frac{\delta_{3i}}{m} \tag{20}$$

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, m.

Cross-sectional budget data do not provide direct information about price responses. Instead, the own-price and cross-price elasticities were obtained using a general property of directly additive utility functions obtained by Frisch (1959) and involving the elasticity of the marginal utility of total expenditure with respect to total expenditure, ξ, often called the Frisch parameter. A value of -1.9 was used below, based on Dixon et al (1982).

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. Surveys have only been conducted tri-annually since 1998. The surveys were then pooled to form one large database. Over this period there were very few changes in indirect taxes. Households were divided into 18 demographic groups, and then further divided into smoking (S) and non-smoking (NS) households; a positive weekly expenditure on tobacco 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 to substantially improve the fit of most of the budget share relationships. With the level of disaggregation used, it was necessary to carry out a total of 792 ($22 \times 2 \times 18$) budget share regressions.

4.2 Changes in Welfare

Table 4 summarises the welfare changes that arise from the $25 carbon tax.[7] The analysis was conducted for a range of total weekly household expenditure levels, though for convenience only three values are shown in the tables for each of the eighteen household groups. The equivalent variation, EV, is given together with its ratio to total weekly expenditure, EV/m. These results show that the welfare loss is generally around 1.4 percent of total expenditure. The relationship between EV/m and m provides an

[7] For the first two household groups, 65+ refers to the age of the head of the household.

indication of the disproportionality of the welfare impact of the carbon tax within each household type. A rising profile may be described as progressive. For nine non-smoking household groups and six smoking household groups, the ratio EV/m decreases with m. 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/m details the increases in tax paid per week, ΔT, which range from \$2.86 to an extra \$14.89 per week and generally increase with the number of individuals in the household along with the household's level of total weekly expenditure.

The marginal excess burden of the carbon tax, MEB, is the difference between the equivalent variation and the increase in tax paid, $MEB = EV - \Delta T$, and provides a measure of the efficiency loss arising from the carbon tax. 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 excess burdens incurred by households with one child rise with expenditure at a greater rate than the burdens incurred by households with no children. Single adult, relative to multi-adult households with higher total expenditure levels, are similarly more adversely affected by the carbon tax. 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 are substantially greater than those incurred by couples where both are aged under 65.

Table 5 reports the welfare changes at arithmetic mean weekly total expenditure levels, $\bar{m}$, for each household type. The welfare loss is about 1.3 percent, while the marginal welfare cost, defined as $MWC = MEB/\Delta T$, varies between approximately 15 and 18 cents for smoking households and between 13 and 15 cents for non-smoking households per dollar of additional tax revenue. These are lower than the costs that are generally thought to apply to income taxes and for more selective commodity taxes (for example on petrol).

Table 4 - Welfare and Tax Changes: Carbon Tax $25

No.	Household Group	m	Non-Smoking EV	Non-Smoking EV/m	Non-Smoking ΔT	Smoking EV	Smoking EV/m	Smoking ΔT
1	65+ Single	300	3.94	0.013	3.48	3.76	0.0125	3.17
		600	7.19	0.012	6.38	6.91	0.0115	5.86
		1000	11.89	0.012	10.01	11.63	0.0116	9.17
2	65+ Couple	300	4.27	0.014	3.78	4.29	0.0143	3.57
		600	7.88	0.013	6.96	7.89	0.0132	6.73
		1000	12.23	0.012	10.93	12.94	0.0129	10.67
3	Single Adult & No Children	300	4.11	0.014	3.57	3.89	0.0130	3.24
		600	7.19	0.012	6.36	7.42	0.0124	6.22
		1000	10.80	0.011	9.48	12.12	0.0121	9.93
4	Single Adult & 1 Child	300	4.07	0.014	3.58	3.89	0.0130	3.37
		600	7.14	0.012	6.16	6.94	0.0116	5.99
		1000	12.15	0.012	9.25	12.39	0.0124	9.67
5	Single Adult & 2 Children	300	3.99	0.013	3.59	3.92	0.0131	3.36
		600	7.36	0.012	6.28	7.41	0.0124	6.25
		1000	14.99	0.015	10.79	13.10	0.0131	10.26
6	Single Adult & 3 Children	300	3.74	0.013	3.28	3.93	0.0131	3.33
		600	7.39	0.012	6.32	6.97	0.0116	5.93
		1000	14.46	0.015	11.15	11.63	0.0116	9.03
7	Single Adult & 4+ Children	300	4.06	0.014	3.59	2.90	0.0097	2.86
		600	7.07	0.012	6.40	7.33	0.0122	6.03
		1000	10.85	0.011	9.38	12.35	0.0124	9.83
8	Adult Couple & No Children	300	4.44	0.015	3.90	4.42	0.0147	3.64
		600	8.16	0.014	7.14	7.91	0.0132	6.77
		1000	12.21	0.012	10.93	12.00	0.0120	10.59
9	Adult Couple & 1 Child	300	4.64	0.016	4.02	4.33	0.0144	3.60
		600	8.19	0.014	7.14	7.99	0.0133	6.74
		1000	12.38	0.012	10.75	12.81	0.0128	10.73
10	Adult Couple & 2 Children	300	4.69	0.016	4.00	4.51	0.0150	3.58
		600	8.18	0.014	7.12	7.83	0.0131	6.74
		1000	12.34	0.012	10.89	12.34	0.0123	10.64
11	Adult Couple & 3 Children	300	4.63	0.015	4.07	5.10	0.0170	4.01
		600	8.16	0.014	7.12	8.31	0.0138	7.17
		1000	12.22	0.012	10.83	12.21	0.0122	10.68
12	Adult Couple & 4+ Children	300	4.61	0.015	3.88	4.59	0.0153	3.66
		600	8.01	0.013	6.96	8.52	0.0142	7.18
		1000	12.46	0.013	10.64	12.76	0.0128	11.08
13	3 Adults & No Children	300	4.49	0.015	3.78	4.11	0.0137	3.19
		600	8.53	0.014	7.33	8.10	0.0135	6.78
		1000	12.98	0.013	11.50	12.66	0.0127	10.94
14	3 Adults & 1 Child	300	5.32	0.018	4.35	5.16	0.0172	4.24
		600	8.92	0.015	7.69	8.53	0.0142	7.29
		1000	13.05	0.013	11.49	12.63	0.0126	10.93
15	3 Adults & 2+ Children	300	4.32	0.014	3.56	3.66	0.0122	2.72
		600	8.42	0.014	7.17	8.43	0.0140	6.64
		1000	13.26	0.013	11.31	13.71	0.0137	11.50
16	4+ Adults & No Children	300	4.51	0.015	3.93	4.11	0.0137	4.08
		600	8.70	0.015	7.33	8.95	0.0149	7.51
		1000	13.15	0.013	11.34	13.13	0.0131	11.38
17	4+ Adults & 1 Child	300	4.92	0.016	4.08	4.79	0.0160	3.66
		600	8.83	0.015	7.47	9.40	0.0157	7.71
		1000	13.50	0.014	11.42	14.89	0.0149	12.57
18	4+ Adults & 2+ Children	300	5.91	0.020	4.99	5.16	0.0172	4.25
		600	9.44	0.016	8.17	8.96	0.0149	7.64
		1000	13.72	0.014	11.87	13.79	0.0138	11.78

Table 5 - Welfare and Tax Changes at Mean Weekly Expenditure

No.	Household Group	Smokers				Non-Smokers			
		$\bar{m}$	EV	$EV/\bar{m}$	ΔT	$\bar{m}$	EV	$EV/\bar{m}$	ΔT
1	65+ Single	267	3.14	0.0128	2.86	274	3.65	0.0133	3.22
2	65+ Couple	498	6.71	0.0135	5.67	540	7.21	0.0133	6.34
3	Single Adult & No Children	406	5.15	0.0127	4.32	437	5.58	0.0128	4.91
4	Single Adult and 1 Child	400	4.89	0.0122	4.23	403	5.12	0.0127	4.50
5	Single Adult & 2 Children	428	5.38	0.0126	4.58	438	5.41	0.0123	4.73
6	Single Adult & 3 Children	468	5.66	0.0121	4.83	475	5.76	0.0121	4.97
7	Single Adult & 4+ Children	501	6.11	0.0122	5.02	539	6.49	0.0120	5.86
8	Adult Couple & No Children	690	8.87	0.0129	7.66	766	9.92	0.0130	8.77
9	Adult Couple & 1 Child	668	8.78	0.0131	7.43	763	9.92	0.0130	8.67
10	Adult Couple & 2 Children	707	8.96	0.0127	7.83	896	11.29	0.0128	10.10
11	Adult Couple & 3 Children	805	10.39	0.0129	9.04	844	10.66	0.0126	9.42
12	Adult Couple & 4+ Children	673	9.34	0.0139	7.95	822	10.51	0.0128	9.05
13	3 Adults and No Children	975	12.40	0.0127	10.69	992	12.90	0.0130	11.42
14	3 Adults & 1 Child	898	11.61	0.0129	10.03	1038	13.41	0.0129	11.83
15	3 Adults & 2+ Children	826	11.50	0.0139	9.42	920	12.35	0.0134	10.52
16	4+ Adults & No Children	1311	16.12	0.0123	14.25	1282	16.03	0.0125	13.96
17	4+ Adults & 1 Child	1110	16.36	0.0147	13.83	1129	14.96	0.0133	12.62
18	4+ Adults & 2+ Children	1070	14.60	0.0136	12.47	925	12.90	0.0140	11.21

5 Changes in Inequality

The relationship between EV/m and m was used in the previous section to provide an indication of the disproportionality, of the impact of the carbon tax. However, this 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 may be examined using the distribution of money metric utility, m_e, before and after the imposition of the carbon tax. A suitable money metric is defined as the value of total expenditure, which, at some reference set of prices, p_r, would give the same utility as the actual total expenditure. This metric was called ‘equivalent income’ by King (1983), but this term can lead to confusion when used in conjunction with adult equivalence scales. 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). It ensures that alternative situations are evaluated using a common set of reference prices, and is invariant with respect to monotonic transformations of utility. Using the expenditure function gives:

$$m_e = E\left(p_r, V\left(p, m\right)\right) \tag{21}$$

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

$$m_e = \sum_{i=1}^{n} p_{ri}\gamma_i + \left\{\prod_{i=1}^{n}\left(\frac{p_{ri}}{p_i}\right)^{\beta_i}\right\}\left\{m - \sum_{i=1}^{n} p_i\gamma_i\right\} \tag{22}$$

The effect on welfare can be measured in terms of a change in m_e from m_{e0} to m_{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, m_{e1} is simply the value of total expenditure after the price change less the value of the equivalent variation; that is, $m_{e1} = m_1 - EV$. Hence the proportionate change, $\left(m_1 - m_{e1}\right)/m_1$, is conveniently the ratio of EV to m_1.

The inequality measures reported here refer to the inequality of individual money metric utilities. Each individual in a household is given that household's value of 'wellbeing', $z = m_e / h$ where h is the adult equivalent size. The inequality measure reported is the Atkinson measure, A, which is based on the additive social welfare function:[8]

$$W = \frac{1}{\sum_{i=1}^{N} n_i} \sum_{i=1}^{N} n_i V\left(z_i\right) \tag{23}$$

where n_i is the number of individuals in the i^{th} household $\left(i = 1, \ldots, N\right)$ and $V\left(z\right)$ is increasing and concave. Define $\tilde{z}$ as the money metric per equivalent adult which, if received by every person, produces the same social welfare as the actual distribution. Inequality is defined as the proportional difference $\tilde{z}$, and the arithmetic mean, $\bar{z}$, so that:

$$A = 1 - \frac{\tilde{z}}{\bar{z}} \tag{24}$$

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

$$V\left(z\right) = \frac{z^{1-\varepsilon}}{1-\varepsilon} \tag{25}$$

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

where $\varepsilon \neq 1$ is the degree of constant relative inequality aversion of a disinterested judge. For $\varepsilon = 1$, the expression in equation (25) becomes $V(z) = \log z$. The coefficient $\varepsilon \neq 1$ is a measure of relative inequality aversion which, as the degree of concavity of $z^{1-\varepsilon}/(1-\varepsilon)$ 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.

To provide a measure of living standard that is comparable across households with different demographic structures, income levels must be adjusted using an adult equivalence scale. This paper adopts a two-parameter functional form of the equivalence scale:

$$h = (n_a + \theta n_c)^{\phi} \tag{26}$$

where n_a and n_c are the number of adults and children in the household respectively. The parameter θ measures the size of children relative to adults, and the term ϕ reflects economies of scale in consumption.[9] On the use of this form, see Jenkins and Cowell (1994, p.894). The results reported here use the values $\theta = 0.65$ and $\phi = 0.75$, which are around the middle of many scales used in the literature. Sensitivity analyses show that inequality rises with θ and profiles of inequality for variations in ϕ are U-shaped. The value of 0.75 corresponds roughly to the minimum inequality measure, for a given value of θ.

Table 6 provides 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. The overall redistributive effect of the tax was an increase in inequality of 0.345 percent. This effect reflects the relative numbers of households in the various demographic groups, as well as the distribution of total expenditure among households.

[9] 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 6 - Inequality Measures: Carbon Tax of $25 per tonne of Carbon Dioxide

No.	Household Type	Inequality Measure					
		Smoking			Non-Smoking		
		Pre-	Post-	%Δ	Pre-	Post-	%Δ
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 Adult & No Children	0.1804	0.1806	0.1109	0.1928	0.1936	0.4149
4	Single Adult & 1 Child	0.0876	0.0879	0.3425	0.1310	0.1315	0.3817
5	Single Adult & 2 Children	0.1027	0.1029	0.1947	0.1318	0.1317	-0.0759
6	Single Adult & 3 Children	0.1140	0.1142	0.1754	0.1270	0.1267	-0.2362
7	Single Adult & 4+ Children	0.0722	0.0721	-0.1385	0.1162	0.1166	0.3442
8	Adult Couple & No Children	0.1285	0.1290	0.3891	0.1670	0.1677	0.4192
9	Adult Couple & 1 Child	0.1237	0.1239	0.1617	0.1658	0.1665	0.4222
10	Adult Couple & 2 Children	0.1072	0.1076	0.3731	0.1749	0.1757	0.4574
11	Adult Couple & 3 Children	0.1656	0.1666	0.6039	0.1463	0.1470	0.4785
12	Adult 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		%Δ: 0.3450	

6 Conclusions

This paper has analysed the potential effects on consumer prices in New Zealand arising from the imposition of a carbon tax rate of $25 per tonne of carbon dioxide. The resulting effects of the 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 levels 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. Even for a high aversion to inequality, the carbon tax was found to give rise to a very small redistributive effect. The marginal welfare cost, reflecting the efficiency of the carbon tax, was found to be around 15 cents per dollar of additional tax revenue. These relatively small burdens and distributional effects could easily be compensated by revenue recycling.

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