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Carbon Taxation, Prices and Inequality in Australia

ANTONIA CORNWELL and JOHN CREEDY[1]

I. INTRODUCTION

Recognition of the adverse effects of carbon dioxide emissions, resulting mainly from the combustion of fossil fuels, has led to proposals for non-market mechanisms such as regulation, and market mechanisms such as tradable emissions permits and carbon taxes, in order to reduce emissions. Market methods are usually preferred in terms of efficiency, and the carbon tax is deemed as being the easiest to implement and monitor. Owen (1992, p. 4) compares carbon taxes with other instruments; Pearce (1991) provides a summary of the advantages and disadvantages of a carbon tax; and Dower and Zimmerman (1992) compare the merits of carbon taxes and tradable emissions permits.

A carbon tax would affect the price of fossil fuels and thus consumer prices, both directly for fuels and indirectly for manufactured goods. These price changes would alter the levels of final demands, and therefore fossil fuel use and aggregate carbon dioxide emissions. This paper investigates the orders of magnitude of a carbon tax required to reduce carbon dioxide emissions in Australia such that the Toronto target is met; this requires a reduction in emissions of 20 per cent of 1988 levels by 2005. The paper also examines the

[1] Antonia Cornwell is at the Industry Commission in Melbourne; John Creedy is the Truby Williams Professor of Economics at the University of Melbourne.
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distributional implications of carbon taxation where allowance is made for consumer responses to price changes and the indirect price effects of taxes.

The approach follows that of Symons, Proops and Gay (1994) for the UK. However, a different type of demand system is used to obtain the many demand elasticities needed. The method focuses on the reduction in emissions resulting entirely from consumer demand responses. The present paper also examines the implications of changes in intermediate requirements in the production process — that is, a change in the input-output matrix. The analysis comprises three stages, which are outlined in the following subsection. The individual components of each stage are more fully explained in Section II. Section III provides information regarding calibration of the model. The simulation results are discussed in Section IV, with the effects of allowing for technological substitution considered in Section V. Brief conclusions are drawn in Section VI.

A Three-Stage Process

The first stage is to apply a carbon tax. If the carbon tax is shifted forward to consumers, it increases the price of goods in proportion to their carbon content. These price changes can be modelled as being equivalent to a set of indirect taxes on consumer goods. The assumption of full shifting is, of course, very strong, requiring competitive markets and constant returns, but it is the standard assumption used in partial equilibrium analyses of indirect taxes. The analysis does not allow for general equilibrium effects, such as changes in factor prices and (pre-tax) goods prices resulting from a carbon tax. If c_i is the carbon dioxide intensity for commodity group i and α is the specific tax on carbon dioxide emissions (measured in dollars per tonne of carbon dioxide), it is possible to calculate the equivalent *ad valorem* tax rate on the ith commodity group, t_i, measured as a percentage of the tax-exclusive value of the commodity group, using the relationship given by Symons et al. (1994, p. 26):

(1) $$t_i = \alpha c_i$$

The second stage is to calculate the demand response of consumers to the price changes. These responses are determined using a method described in Cornwell and Creedy (1995) which makes use of Australian Household Expenditure Survey (HES) data to calculate all the own- and cross-price demand elasticities for various commodity groups in a range of income groups. The approach assumes no labour supply responses. New expenditure levels are calculated for each household, from which the amount of indirect tax paid on all goods is subtracted, giving total net consumption. Measures of inequality and progressivity are then based on the change in net consumption.

The final stage is to calculate the new levels of aggregate demand for each commodity group in order to determine the reduction in carbon dioxide emissions. Hence the reduction in emissions is obtained at the last of the three stages and, because of the complexity involved in each of the three stages, it is not possible to calculate directly the value of α that would achieve a specified reduction in emissions. This requires an iterative search procedure involving the use of an arbitrary initial value of α and then a gradual process of adjustment involving the repeated application of the three stages until the desired reduction in emissions is produced.

The first and third stages described above use the same input-output matrix, so that carbon dioxide reductions result only from consumer substitution. That is, following Symons et al. (1994), it is assumed that there is no substitution in production and all substitution falls on the demand side. This assumption is made due to the lack of information on, and widely varying estimates of, possible substitutions in production; see Owen (1992, p. 5). However, it is likely that there would be a relatively large amount of substitution in production if a carbon tax were imposed in Australia. Hence, it is of interest to calculate the potential effect on emissions of specified changes in the input-output matrix.

II. THE ANALYTICAL FRAMEWORK

1. Carbon Tax and Price Changes

A carbon tax is imposed on the carbon content of fuels used in production and consumption, rather than carbon dioxide emissions, and hence the majority of studies specify carbon taxes in terms of dollars per tonne of carbon. However, as carbon content and carbon dioxide emissions are directly proportional, a carbon tax can be converted to a tax on carbon dioxide emissions merely by multiplying the former by the relative elemental weight of carbon to carbon dioxide. Carbon has a weight of 12 and oxygen a weight of 16; therefore CO_2 has a total weight of 44 and the relative weight of carbon to carbon dioxide is approximately 0.272727. For example, a carbon tax of \$100 per tonne of carbon is equal to a tax of \$27.27 per tonne of carbon dioxide emissions.

To calculate the set of equivalent indirect taxes according to equation (1), it is necessary to have the carbon tax specified as a tax on carbon dioxide emissions. It is also required to know the carbon dioxide intensities, c_i ($i = 1,...,n$), of the n commodity groups involved. Carbon dioxide emissions are largely the result of the combustion of fossil fuels and arise from the production and consumption of goods. When calculating the emissions from consumption, it is appropriate to consider only domestic consumption; final demand figures for fossil fuels are therefore adjusted to exclude exports and the stockbuilding of fuels. Data on carbon dioxide emissions resulting from sources other than the combustion of fossil fuels are not available for Australia. In determining emissions from production, it is not enough to consider only final products; gross output, allowing for inter-industry trade, must be considered.

Define the following variables, where vectors are columns and coefficients are in value terms:

- e is the k-vector of carbon dioxide emission per unit of fossil fuel use (for k fossil fuels);
- P is the $n \times k$ matrix of household fuel requirements per unit of final demand, for each producing sector and for each fossil fuel;
- Z is the $n \times n$ matrix of weights, to exclude from consideration the export and stockbuilding of fuels;
- C is the $n \times k$ matrix of production fuel requirements per unit of total demand, for each producing sector and for each fossil fuel;
- A is the $n \times n$ matrix of technological coefficients, relating the inputs to each producing sector to the total outputs by the sectors;
- x is the n-vector of final demand for each sector.

Carbon dioxide emissions can be expressed as a weighted sum of final demands. Following Proops, Faber and Wagenhals (1993, p. 127), total emissions, E, are

$$(2) \qquad E = \left[e'\, P'\, Z + e'\, C'\, (I - A)^{-1}\right] x$$

where a prime indicates transposition. By adjusting equation (2) such that the x vector becomes the leading diagonal in a matrix with all other elements equal to zero, the resulting expression gives a vector of emissions for n sectors of the economy, which is precisely the information required to calculate a set of indirect taxes according to equation (1).

2. Demand Responses and Tax Revenue

From the price changes, it is possible to calculate the demand responses of consumers using demand elasticities that vary with household income. From the new demands, and using the equivalent tax-inclusive indirect rate, it is possible to determine the amount of indirect tax paid and hence net total expenditure. Let y denote the total expenditure of a household, consisting of expenditure on each of n commodities, where consumption of the ith commodity is denoted q_i (i = 1,...,n). If prices are denoted by p_i (i = 1,...,n), the demand function for good i is

$$(3) \qquad q_i = q_i(p_i, .., p_n \,|\, y)$$

If $\dot{p}_j = \mathrm{d}\, p_j / p_j$

where dp_j denotes a small change in p_j and e_{ij} is the cross-price elasticity of demand for good i with respect to a change in the price of good j, (dq_i/q_i) / (dp_j/p_j), then the change in the level of expenditure, m_i, resulting from price changes is given by

(4) $$\mathrm{d}\, m_i = p_i q_i (\dot{p} + \Sigma_j\, e_{ij}\, \dot{p}_j\,)$$

As explained above, the price changes are considered to result from a commodity tax equivalent to the carbon tax. Suppose, as before, that t_i denotes the tax-exclusive consumption tax rate on good i, so the tax-inclusive price of the good is 1+ t_i multiplied by the tax-exclusive price. Hence the introduction of a consumption tax translates into a proportional change in the price. The equivalent tax-inclusive rate is given by t_i /(1+ t_i). Hence the tax revenue from the ith good after the price change, R_i, is given by

(5) $$R_i = \left(\frac{t_i}{1+t_i}\right) m_i$$

The new revenue arising from changes to the indirect tax rates can therefore be obtained by using equation (4) to find m_i and then using equation (5).

3. Demand Elasticities

The number of demand elasticities required is obviously very large. Even with the high level of aggregation of the data in this paper, with 14 commodity groups and 30 income groups, it is necessary to determine just under 6,000 own- and cross-price elasticities. Because of the paucity of household expenditure data in Australia, it is not possible to produce the type of econometric estimates for different population groups as used by Symons, Proops and Gay (1994). The method used in this paper instead follows that described in Cornwell and Creedy (1995). This method has the advantage of not requiring price information but has the corresponding disadvantage that it uses price elasticities based on theoretical restrictions rather than observed responses to price changes (although econometric estimates using time-series data also require strong restrictions to be imposed). A brief summary of the process is given here.

The first stage in calculating the elasticities is to obtain the total expenditure elasticities for each commodity group and level of total expenditure. The total expenditure elasticities are obtained by using a matrix with K rows, for the total expenditure levels, y_k (k = 1,...,K), such that each row contains the budget shares,

$w_{ki} = p_{ki}\, q_{ki} / y$, for each of the n commodity groups. The n elasticities for the kth total expenditure group can be found using the approximation

$$(6) \qquad e_i = 1 + \frac{\Delta w_i / w_i}{\Delta y / y}$$

where the k subscripts have been omitted for convenience and, for example, Δw_i denotes the change in the budget share of the ith commodity when moving from total expenditure group k to group k+1.

Having determined expenditure weights and the total expenditure elasticities, it is possible to calculate price elasticities by proceeding on the assumption that

preferences are additive, such that utility is expressed $\sum_i u_i(q_i)$

In this special case, Frisch (1959) demonstrated that the price elasticities can be written for $i \neq j$ as

$$(7) \qquad e_{ij} = -e_i\, w_j (1 + \frac{e_j}{\xi})$$

and for $i = j$ as

$$(8) \qquad e_{ii} = \frac{e_i}{\xi} - e_i\, w_i (1 + \frac{e_i}{\xi})$$

where ξ is the total expenditure elasticity of the marginal utility of total expenditure, usually referred to as the Frisch parameter. These expressions automatically satisfy the homogeneity and additivity restrictions. Additive preferences imply that all goods are net substitutes, so that when p_j rises, the compensated demand for good i rises. Additivity is more easily justified for broad commodity groups, as used here, but for a criticism of the implications of employing the additivity condition, see Deaton (1974). The Frisch approach has been used extensively in Australian demand studies; see, for example, Tulpule and Powell (1978) and Williams (1978).

Expressions (7) and (8) allow the price elasticities to be calculated using only household budget data. Budget data provide information about the budget shares, w_i, and hence the total expenditure elasticities, e_i, but it is necessary to specify the Frisch parameter using extraneous information. The question arises as to whether the Frisch parameter varies with income and, if so, the form of such variation. Frisch (1959, p. 189) argued for a falling range of values with income, and suggested values of -10 for the very poor, -2 for the 'median part' of the population, -0.7 for the 'better off part' and -0.1 for the 'richer part'. It is not clear how he determined these values, although empirical support for Frisch's conjecture was found by Lluch, Powell and Williams (1977).

The demand responses, or changes in total expenditure, calculated using the above method are in value terms. The input-output framework is also in value terms, so in order to calculate the new level of emissions after the imposition of a carbon tax, it is necessary to convert the changes in total expenditure to constant price equivalents. The resulting levels of total expenditure are then fed back into equation (2) to determine the new level of carbon dioxide emissions.

4. The Simulation Approach

It would be possible to apply the three-stage procedure to individual households in the HES, which is the approach taken by Symons, Proops and Gay (1994) using the UK Family Expenditure Survey and a set of demand functions estimated from a time series of Family Expenditure Surveys allowing for differences in household composition. However, this paper has not obtained elasticities for different household types (because of the data limitations mentioned above), and instead uses a simulated population. The use of a simulated distribution of household incomes provides a sufficiently good description of the actual distribution, and avoids the need to deal with grossing up and other issues. Household incomes are simulated from a log normal distribution, having a mean and variance of logarithms of 10 and 0.5 respectively, which provides a good approximation to the Australian household income distribution in 1984; see Creedy (1992).

TABLE1

Income Tax Rates and Thresholds, 1984-85

Threshold	*Marginal Tax Rate*
A$4,595	0.2667
A$12,500	0.3000
A$19,500	0.4600
A$28,000	0.4733
A$35,000	0.5533
A$35,788	0.6000

An income tax structure is applied directly to incomes. A stylised transfer payment system is specified so that it is possible to consider the question of whether adjustments to transfer payments can offset the negative effects of a carbon tax. Transfer payments are modelled using a minimum income guarantee (MIG), such that if after-tax income falls below a minimum level, then a transfer is paid to bring net income up to the minimum level.

For each household, an income level is simulated. The income tax structure is applied and post-tax income is calculated. The income tax structure is taken directly from the Australian income tax schedule, and the income tax rates and thresholds used are given in Table 1. Post-tax income is adjusted, where appropriate, using the MIG. This post-tax income gives the level of total expenditure, y. It is then possible to find to which expenditure group the household belongs, and therefore the appropriate set of income and price elasticities. In popular debates, it is often argued that consumption taxes are regressive because the relatively rich save a higher proportion of disposable income. However, such savings are ultimately spent and will therefore incur the consumption tax, in addition to any interest-income tax. In the absence of an interest-income tax, the present value of tax payments is independent of the time pattern of consumption. The approach adopted in this paper is therefore to ignore savings.

When a new indirect tax is introduced, the new levels of expenditure are calculated for each household using equation (4). From this information, the amount of indirect tax paid on each taxed good is determined using equation (5). This is then subtracted from each household's disposable income to find net consumption. Progressivity and income inequality measures can be calculated using net consumption to provide information regarding the distributional implications of changing the indirect tax structure. Basing these calculations on net consumption represents what is often referred to as a non-welfarist approach.

III. CALIBRATING THE MODEL

First, it is necessary to determine the total level of carbon dioxide emissions, using equation (2), before a carbon tax is imposed. Cornwell (1996) has calibrated this equation for Australia. The majority of the data are from two sources. Information on total energy consumption by industry and fuel type are given in Australian Bureau of Agricultural and Resource Economics (1990, Table C1, pp. 78-90). Only the data for the financial year 1989-90 relating to the six primary fuels wood, bagasse, black coal, brown coal, oil and gas were used. The National Accounts Input-Output Tables for 1989-90 provide data on inter-industry flows in value terms; see Australian Bureau of Statistics (1994, Table 5, microfiche and Table 11, pp. 46-8). The 28-sector, as opposed to the 109-sector, classification was used as price changes and demand changes arising from a carbon tax need to be reconciled with the 14-commodity grouping of the HES data. Furthermore, the energy data are not available at a highly disaggregated level.

Second, information is required on household expenditure patterns and their elasticities, which determine demand changes resulting from changes in prices. Data from the 1984 HES were used for expenditure by households on 14 different commodity groups, divided into 30 income categories. The method of deriving the elasticities, using the basic approach described above, is described in detail in Cornwell and Creedy (1995, pp. 8-10). It involves using smoothed budget shares to determine a set of total expenditure elasticities, from which price elasticities are obtained. In calculating the price elasticities, it is appropriate, given the evidence of Lluch, Powell and Williams (1977), to assume that the Frisch parameter varies with total expenditure. By experimenting with alternative hypothetical sets of combinations of ys and ξs, and using these to estimate alternative functional relationships, it was found that the following equation produced a set of values of ξ that follows the type of variation described by Frisch (1959, p. 189) and stated earlier:

(9) $\log(-\xi) = 18.57 - 1.72 \log$

This equation produces a set of Frisch values ranging approximately from -0.2 to -11.4. Due to the lack of a solid foundation for deriving the Frisch values, both a smaller and a larger variation in the values with income were also considered. However, it was found that the general results were unaffected and, furthermore, the differences in the absolute values of the inequality, progressivity and welfare measures reported below were minimal. Hence this paper reports only the results of using the Frisch values determined according to equation (9).

Once the input-output data have been used to obtain the pre-tax level of carbon dioxide emissions, they are used to calculate a set of indirect taxes equivalent to a particular carbon tax, using equation (1). These indirect taxes are implied price changes for the 28 input-output categories. However, the HES data are available only for 14 consumption categories, using a different classification from the 28 input-output sectors. It is necessary to translate the 28 price changes into 14 price changes so that demand responses can be calculated. The resulting set of total expenditure (final demand) changes must then be translated back to the 28-sector classification so that the new level of carbon dioxide emissions can be determined. Details of both translations are given in the Appendix.

IV. SIMULATION RESULTS

There are three main issues of initial concern. First, what is the order of magnitude of a carbon tax required to reduce emissions in Australia such that the Toronto target is met? Second, what is the distributional impact of such a tax? Third, is it possible to overcome the negative impact of a carbon tax by increasing transfer payments?

TABLE 2

Indirect Tax Rates to Reduce Emissions by 20 per cent

	14-sector HES classification	*Tax rate t_i*
1	Current housing costs	0.0440
2	Fuel and power	1.3609
3	Food	0.1030
4	Alcoholic beverages	0.1069
5	Tobacco	0.1069
6	Clothing and footwear	0.0461
7	Household furnishings and equipment	0.0726
8	Household services	0.0226
9	Medical care and health	0.0000
10	Transport	0.0885
11	Recreation	0.0834
12	Personal care	0.0000
13	Miscellaneous goods and services	0.0408
14	Others	0.1660

The calculation of the required carbon tax can only be achieved by a search process of trial and error, involving the repeated use of the above three-stage procedure until a value of α is found that generates the desired reduction in emissions. With a constant minimum income guarantee of A$8,000, the carbon dioxide tax — the value of α, as in equation (1) — required to reduce emissions in Australia by 20 per cent from the 1989-90 figures was found to be 0.113, which is a tax of A$113 per tonne of carbon dioxide or A$414 (US$306) per tonne of carbon. This target is slightly stricter than the Toronto target, which refers to 1988 levels, but was used because the input-output data were only available for the year 1989-90. The equivalent set of indirect taxes for this level of carbon tax is given in Table 2. Symons, Proops and Gay (1994, pp. 23 and 28) report that the required tax for the UK is US$411 per tonne of carbon, which is considerably higher. It is not clear if the UK faces lower demand elasticities, or if the difference arises from the structure of inter-industry transactions.

Looking at Table 2, it is of interest to note for which sectors the price increases are the greatest. It is not surprising that fuel and power (2) faces by far the biggest increase. Combined with the fact that lower income earners spend a higher proportion of their budget than higher income earners on fuel and power, this suggests that a carbon tax is regressive. Furthermore, food (3) and tobacco (5), which also face relatively large price increases, also form a higher proportion of the budget of lower income earners. Another factor to consider is that for goods on which lower income earners spend a relatively higher proportion of their budget, the lower income earners have relatively lower price elasticities compared with higher income earners, and therefore have less scope for substitution. However, there are also sectors facing relatively large price increases on which lower income earners spend proportionately less. The price increase for others (14) is the second largest after fuel and power, yet the proportion of total expenditure spent on this sector increases with income. This relationship is also true of recreation (11). For transport (10), the relationship is a humped shape. Therefore, although it appears that a carbon tax may well reduce the degree of progressivity and increase inequality, its effect is not unambiguous.

The distributional impact of the tax can be assessed using a variety of measures. The Gini measure is a very commonly used measure of inequality, and can be related to the famous Lorenz curve diagram which plots the proportion of people against the corresponding proportion of total income, when incomes are arranged in ascending order (the Gini measure is an area-based measure of the distance of the actual Lorenz curve from the diagonal line of equality). The Reynolds-Smolensky measure is an index of the redistributive impact of the tax system; it is obtained as the difference between the Gini inequality measures of pre-tax and post-tax income.

The Kakwani progressivity measure is a measure of the disproportionality of tax payments. It is also based on ideas relating to the Lorenz diagram. If, instead of plotting the proportion of total income against the corresponding proportion of people, a curve is plotted showing the proportion of total tax paid against the proportion of people (with people ranked in ascending order by pre-tax income), then a curve called the tax concentration curve is obtained. A tax concentration measure similar to the Gini inequality measure can be obtained for this curve. For a proportional tax system, the tax concentration curve obviously coincides with the Lorenz curve of pre-tax incomes. Hence the disproportionality of tax payments can be measured as the difference between the tax concentration measure and the Gini measure of pre-tax incomes.

TABLE 3

Distributional Results of a Carbon Tax of A$414 per Tonne of Carbon

Distributional measure	*Pre-carbon-tax value*	*Post-carbon-tax value*
Gini measure of inequality	0.2778	0.2838
Kakwani measure of progressivity	0.2050	0.1429
Reynolds-Smolensky measure	0.1004	0.0944
Total tax ratio	0.3287	0.3977
Welfare premium from progression	1.8779	1.5848

The social welfare premium from progression is defined as the additional welfare from the tax structure, compared with the welfare from a proportional tax raising the same revenue, using the Gini-based social welfare function $\bar{y}(1-G)$ where $\bar{y}$ is the arithmetic mean value of y and G is the Gini measure of inequality; for further information on alternative measures, see Lambert (1993).

These measures were calculated, using a minimum income guarantee of A$8,000, both before and after the carbon tax is introduced. The results are reported in Table 3. It can be seen from these results that the carbon tax reduces the degree of progressivity and has adverse distributional effects. For example, the Gini inequality measure increases by 2.16 per cent, the Kakwani progressivity measure decreases by 30.29 per cent and the Gini-based welfare premium decreases by 15.61 per cent. The effect of the carbon tax on the price of fuel and power is, therefore, driving the results. Alternative summary measures, not reported here, also gave similar results.

In analysing the distributional impact of a carbon tax to achieve the Toronto target, Symons et al. (1994) only consider inequality indices. They give results for the Gini measure of inequality and for three levels of inequality aversion (0.1, 1.0 and 10.0) for the Atkinson inequality measure. Regarding the Gini measure, not only are the absolute values for Australia less than those for the UK, but also the increase in inequality of 2.16 per cent reported here is less than that of 2.92 per cent reported by Symons et al. (1994, p. 32). This is consistent with the assumption that UK consumers are less able to substitute away from goods with high carbon contents than Australian consumers; therefore the set of indirect taxes to achieve the Toronto target level of emissions reduction would need to be higher for the UK than for Australia, giving rise to the result that a carbon tax increases inequality proportionately more in the UK.

TABLE 4

Atkinson Measures of Inequality and the Welfare Premium

Inequality aversion parameter	*Pre-carbon-tax inequality*	*Post-carbon-tax inequality*	*Welfare premium (×0.001)*[a]
0.1	0.0216	0.0132	0.1844
0.5	0.0607	0.0634	0.8646
0.8	0.0944	0.0985	1.3221
1.0	0.1158	0.1207	1.5842
1.2	0.1363	0.1420	1.8765
2.0	0.2094	0.2175	2.8622

[a]The welfare premium before the carbon tax is 1.8779.

For the purpose of comparison, Atkinson measures are shown in Table 4. The level of aversion of 10.0 used by Symons et al. (1994) is not used here as this effectively amounts to a maxi-min criterion, which aims to maximise the income of the poorest person. With a level of aversion of 0.1, as with the Gini measure, both the absolute values and the percentage increases in inequality are less for Australia than for the UK; the absolute values are less by a factor of approximately ½, and the percentage increases are 4.76 per cent and 6.62 per cent respectively. The same result holds with a level of aversion of 1.0. For Australia, the lower is the aversion parameter, the higher is the percentage increase in inequality. This trend does not hold with the results obtained by Symons et al. (1994, p. 32).

The above carbon tax involves a revenue-increasing change; the overall effective tax ratio increases from 0.3287 to 0.3977. It is of interest to see whether the negative effects of introducing a carbon tax can be overcome by using some of the extra revenue to increase transfer payments whilst still achieving the Toronto target level of emissions reduction. If the minimum income guarantee is increased, then this affects consumption patterns on top of the changes brought about by the tax, which will lead to a lessening in the reduction of emissions, given that fuel is a higher proportion of total expenditure of low income groups. This is partially compensated by the fact that increasing the MIG pushes lower earners into a higher income bracket, which means they then have higher elasticities and so are able to substitute away from relatively heavily taxed carbon-intensive goods more easily. However, to increase the MIG and meet the Toronto target, the carbon tax rate also needs to be increased. But an increase in the carbon tax rate leads to a worsening effect on inequality and progressivity. The question is whether or not it is possible to reach a convergence such that the negative effects of the carbon tax are overcome whilst still attaining the target level of reductions and not reducing total revenue. The answer is that it is possible to do so. For example, it was found that with a carbon dioxide tax of 0.15, which translates to a tax of A$550 (US$743) per tonne of carbon, and a MIG of $12,000, inequality decreased, progressivity increased and the welfare premium increased, whilst carbon dioxide emissions were reduced by 21.6 per cent and total revenue actually increased. It would be possible to determine a tax rate and MIG that reduce emissions by exactly 20 per cent and are also revenue-neutral; however, the results are sufficient to demonstrate that the negative effect of a carbon tax can be compensated by adjustments to transfer payments.

V. TECHNOLOGICAL SUBSTITUTION

The above results assume that the consumer bears all the substitution required to reduce emissions, as in Symons, Proops and Gay (1994). Pearce (1991), in his review of carbon taxes, presents estimates of the levels of tax that would reduce emissions by roughly 20 per cent in each of the UK, the US and Norway, where allowance is made for long-run substitution in production. The average of the figures is US$174 for the UK, US$149 for the US and US$126 for Norway per tonne of carbon. For Australia, McDougall (1993, p. 8) uses a carbon tax of A$80 (US$59) per tonne of carbon, which he takes from a study reported by the Industry Commission (1991, p. 189). However, the tax allows for an unspecified amount of substitution in production. Despite the difficulties entailed, it would be useful to have some idea of the orders of magnitude involved in allowing for substitution in production. One approach is to examine the changes to the input-output matrix that would be required to reduce emissions by approximately 20 per cent with a tax rate closer to the estimates summarised by Pearce (1991). These studies produced tax rates to achieve the Toronto target that are approximately half the size of the A$414 per tonne of carbon (0.113 carbon dioxide) tax rate reported above as being the level necessary to achieve the target without technological substitution. Therefore the distributional implications of a tax of A$200 per tonne of carbon (a carbon dioxide tax of 0.055) were examined, along with the corresponding degree of technological substitution necessary to reduce emissions to the Toronto target level.

There are, of course, limitless combinations of changes that would achieve the desired reduction in emissions. However, it is appropriate to consider the effects of a substitution in production away from fuels with high carbon contents and towards gas, along with a general reduction in all inputs used by industries producing high amounts of carbon dioxide. The following assumptions were therefore based on close study of the emissions and carbon contents per dollar in each industry, along with industries that experience high price changes resulting from a carbon tax, although the actual values are to some extent arbitrary. Suppose there is a 12 per cent reduction in the use of sectors 10, 11 and 12 as inputs to other sectors, a 25 per cent increase in the use of gas (18) as an input and a 4 per cent decrease in the use of all inputs in production in sectors 2, 4, 5, 9-13, 17, 20, 23, 26, 27 and 28. It was found that emissions are reduced by 19.4 per cent with a carbon tax of A$200. Given that the time frame in which these changes would need to occur would be in the vicinity of 10 to 20 years, these rates are not excessive.

The distributional impact of a carbon dioxide tax of 0.055 with the above changes is that the Gini measure of inequality increases by 0.9 per cent, the Kakwani progressivity measure decreases by 14.39 per cent and the Gini-based welfare premium decreases by 6.75 per cent. These figures are markedly less adverse than those for the tax of 0.113 where there was no allowance for substitution in production, which were 2.16 per cent, 30.29 per cent and 15.61 per cent respectively. This result is expected, given that most of the reduction in emissions with the tax of 0.055 is attributed to substitution in production, not consumption. Indeed, it was calculated that of the 19.4 per cent decrease in emissions, 8.2 percentage points are attributed to changes in consumption.

VI. CONCLUSIONS

This paper has examined the orders of magnitude of a carbon tax required to reduce carbon dioxide emissions in Australia such that the Toronto target is met. It has also looked at the effects on inequality and progressivity of carbon taxation where allowance is made for both consumer responses to price changes and the indirect price effects of taxes. The approach was to model a carbon tax as a set of *ad valorem* taxes on commodity groups. Input-output data were required to calculate the appropriate tax rates, and Household Expenditure Survey data were used to determine consumers' responses to the price changes. However, given that assuming no substitution in production is unrealistic, this paper also investigated the effect of allowing for substitution in production. Although the order of magnitude of a carbon tax to reduce emissions in Australia by 20 per cent, assuming no technological substitution, is high (at A$414 or US$306 per tonne of carbon), it is less than that calculated by Symons, Proops and Gay (1994) for the UK (US$411). Furthermore, the distributional implications of the tax are also less adverse for Australia. Nevertheless, such comparisons need to be treated with caution, given the differences in approach and types of data used.

The carbon tax involves an increase in total tax revenue and a reduction in the degree of progressivity, with an increase in inequality. However, it was found that transfer payments can be adjusted to compensate for the regressivity of a carbon tax without decreasing total revenue.

APPENDIX: TRANSLATION BETWEEN COMMODITY GROUPS

The translation between the 14-sector Household Expenditure Survey commodity grouping and the 28-sector input-output classification, for the price changes and the corresponding demand changes, are given in Table A. For the process of translating the 28 price changes into 14 price changes, for sectors where there is only one of the 28 sectors related to one of the 14 groups, the price change was obviously translated directly. For the cases where there are several 28-sector classifications relating to one 14-group classification, the price change for the group category was taken as a weighted average of the related sector price changes, with the weights being the proportional contribution to the sum of the final demands for those sectors. For groups 9 and 12 of the 14 groups, there were no input-output sectors deemed appropriate, and so the price changes in these two groups were assumed to be zero.

The 14-group price changes are then used to determine the demand responses of households as described in Section II. Table B gives the new demands as a proportion of the pre-tax demands resulting from a carbon tax of A$414 estimated to reduce carbon dioxide emissions in Australia by 20 per cent, where a constant minimum income guarantee of A$8,000 is assumed. Once the 14

TABLE A

Translation between 14-Group and 28-Sector Classifications

	14-group HES classification		*28-sector input–output classification*	*Carbon dioxide intensity (emissions per dollar of output)*
1	Current housing costs	24	Finance, property etc.	0.3891
2	Fuel and power	10	Petroleum and coal products	12.802
		17	Electricity	13.121
		18	Gas	1.6027
3	Food	3	Meat and milk products	0.6988
		4	Food products	1.1365
4	Alcoholic beverages	5	Beverages, tobacco products	0.9465
5	Tobacco	5	Beverages, tobacco products	0.9465
6	Clothing and footwear	6	Textiles, clothing, footwear	0.4083
7	Household furnishings and equipment	7	Wood, wood products	0.6429
8	Household services	25	Ownership of dwelling services	0.2003
9	Medical care and health	—	—	—
10	Transport	14	Transport equipment	0.7669
		23	Transport, communication	0.7914
11	Recreation	28	Recreational etc. services	0.7383
12	Personal care	—	—	—
13	Miscellaneous goods and services	8	Paper, printing etc.	0.4655
		16	Miscellaneous manufacturing	0.5397
		21	Wholesale and retail	0.3564
		22	Repairs	0.4270
		27	Community services	0.3472
14	Others	1	Agriculture, forestry, logging	0.8285
		2	Mining	0.8248
		9	Chemicals	0.9738
		11	Non-metallic mineral products	1.6240
		12	Basic metals and products	2.9014
		13	Fabricated metal products	1.0337
		15	Machinery etc.	0.6256
		19	Water	0.9910
		20	Construction	1.7427
		26	Public administration, defence	0.8479

TABLE B

New Demands from a Carbon Tax of A$414 per Tonne of Carbon

	14-sector HES classification	*Demand as a proportion of pre-tax value*
1	Current housing costs	0.9537
2	Fuel and power	0.7335
3	Food	0.9247
4	Alcoholic beverages	0.8594
5	Tobacco	0.9379
6	Clothing and footwear	0.9009
7	Household furnishings and equipment	0.8638
8	Household services	0.9573
9	Medical care and health	0.9509
10	Transport	0.8609
11	Recreation	0.8679
12	Personal care	0.9454
13	Miscellaneous goods and services	0.9017
14	Others	0.7210

demand changes were calculated, it was necessary to translate these back up into the 28-sector classification in order to determine the final effect on the level of carbon dioxide emissions using equation (2). For all input-output sectors except 5, 19 and 26, the figure translated was simply that calculated for the corresponding HES group. For input-output sector 5, a weighted average of the demand response from HES groups 4 and 5 was used, where the weights were 0.65 and 0.35 (approximately the respective proportions of the two groups to the sum of their new levels of expenditure). For input-output sectors 19 and 26, there were no HES sectors considered appropriate, and thus it was assumed that there was no change in the level of demand for these sectors.

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