Carbon Taxes and Inequality

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Abstract

This paper assesses the distributional impacts of carbon taxes on households by considering both the demand and the supply channels, through which an environmental policy might have an incidence on inequality. Using equivalent income as households' welfare metric and concentration indices as decomposition methods of showing inequality by components, our simulation results suggest that income losses through factor prices concentrate towards rich people as carbon prices increase, implying that the incidence of pollution tax on the source-side of income is progressive. Conversely, the incidence of pollution tax on the use-side (i.e., through commodity price changes) of income is regressive. However, due to the stronger incidence from factor prices, the combined effects of factor and commodity prices tend to reduce inequality following an increase in a carbon tax.

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1 Introduction

It is generally perceived that the imposition of carbon taxes may not proportionally affect the metrics of individual household welfare. Asking whether a carbon tax is progressive can be seen as a provocative questioning. The reality is that the impact of a carbon tax on households (progressive or regressive) is still questionable in light of the differences in its incidence on inequality, particularly when assessed from either the demand or supply sides of household welfare metrics.

Indeed, most studies rely on the demand-side channel in their assessments of the impact of carbon taxes on relative prices of commodities. These studies generally find that carbon taxes exert a regressive impact on household welfare. The main reason behind these findings is that the increase in the prices of energy and energy-intensive goods, brought about by a carbon tax, hurts the poor more than the rich, as the former spend a larger proportion of their income on those goods than the latter do.

For example, Robinson (1985) finds that the incidence of industrial pollution abatement tax is heavily regressive.[1] Similarly, Hamilton and Cameron (1994) analyze the distributional effects of a carbon tax on Canadian households and find that the consequences of the tax are regressive. Wier et al. (2005) and Dinan and Rogers (2002) find similar results for Denmark and the Netherlands, respectively. Kerkhof et al. (2008) and Shammin and Bullard (2009) further confirm these results for the U.S. economy. All these studies have ignored the impact of carbon taxes on factor incomes, and ultimately on inequality. As long as a carbon tax policy carries differentiated implications for factor remunerations, the sources of income gain importance in the assessments of the the policy's impact on inequality.

[1] See also Dubin and Henson (1988).

Taking into account the fact that the rich derive most of their income from capital, compared to the poor, assessing the impact of a carbon tax policy on inequality has the potential to provide completely new insights.

Within a general equilibrium setting, Fullerton and Heutel (2007) have shown that pollution control policies can harm the remuneration of capital more than that of labour. The main reason for this is that the polluting industries are more capital intensive than other industries (see Hettige et. al. (1992)). Implementing policies that affect negatively the former industries will be detrimental to the factor they use intensively. Under these circumstances, and looking from the factor income perspective alone, implementing a pollution control policy could have a progressive impact as the income of the affluent will be more negatively affected than that of the poor. It is important to note that we are not referring to the impact of the policy on social welfare, but rather on inequality; here, we are interested in its distributional impacts. Moreover, the progressiveness of the carbon tax policy, which we are referring to, does not stem from a revenue-recycling approach, as argued by Burtraw et al. (2009) and Bento et al. (2009)

Unfortunately, most of the studies found in the literature on the incidence of pollution control policies on inequality have exclusively considered the demand-side channel, i.e., their impact on the relative prices of commodities.[2] Yet, individual household welfare depends not only on commodity prices, but also on income. This suggests that most of the analyzes on the impact of carbon taxes on inequality are incomplete as they overlook an important channel, that is, their impact on inequality through factor incomes.

Our objective in this paper is to offer a comprehensive analysis of the distributional impact of carbon taxes considering both the demand and the supply channels through which a policy might have an incidence on inequality. When viewed from this more holistic perspective, there is no definitive answer as to the impact of pollution control policies on inequality. This is attributed to the presence of two opposing effects: a regressive impact through the relative prices of commodities, and a progressive impact through factor remuneration.

The final impact is an empirical matter that deserves to be investigated. We assess the possibility of a carbon tax being progressive, i.e., whether there exists some value of a carbon tax, where its positive impact on household welfare distribution through the supply side outweighs its negative impact induced through the demand side. We are not aware of any other paper that offers an analysis of the incidence of carbon taxes on inequality, while disentangling the differing effects arising from both the supply- and the demand-side channels. To do so, we combine general equilibrium analysis with income distribution analysis. A very recent US study by Metcalf et al. (2010) raises the issue of considering the income side in the analysis of the incidence of climate change policies. Nevertheless, their analytical framework is completely different from the one we suggest in this paper.[3]

[2] One notable exception to this is the recent paper by Araar et al. (2011) that analyzes the incidence of carbon mitigation policies on social welfare.

[3] They analyze the effects of different emissions and revenue allocating approaches on household welfare measured in terms of equivalent variation. In contrast, we consider equivalent income

Among one of the earlier studies on the change in income distribution by factor components are Fei et al. (1978) who evaluate the U-shaped impact of growth on income distribution using an econometric approach to estimate the parameters. They argue that the weighted average estimator of the factor Gini coefficients, which they call "pseudo-ginis", can represent the true Gini if their nonlinearity error term is small. Nevertheless, Shorrocks (1983) suggests that the "pseudo-gini" does not generate a unique decomposition formula; it rather represents only one decomposition method among other infinite possibilities. They also argue that the nonlinearity error term may not always be insubstantial. Lerman and Yithzaki (1985) introduce a new approach to estimate the income inequality effect by income sources. Using a natural approach, they show that each source's contribution to Gini coefficient may be taken as the product of the source's own Gini, its share of total income, and its correlation with the rank of total income. Later on, Shorrocks (1999) and Chantreuil (1999) introduce the Shapley value as an exact substitute of the natural approach. The advantage of the Shapley decomposition approach is its simplicity and its avoidance of complex econometric techniques. However, some papers, such as Sastre and Trannoy (2002), have addressed one of the difficulties of using the Shapley decomposition method, i.e., its assumption of independency of inequality of a given income source from others.[4] Makdissi and Woddon (2004) show that the problem of interdependency can be controlled at some level.[5]

An alternative approach showing income inequality by factor components is one introduced by Rao (1969). According to this approach, an inequality index of a variable can be decomposed as a weighted sum of the concentration indices of the component variables that add up to that variable. One advantage of using this approach is that it makes it possible to show the contribution of each component of a variable in an ex-post inequality index. In this paper, we apply the concentration ratios to analyze the decomposition of distributional impacts brought about by an environmental tax.

We develop a static, multi-sector, and multi-household general equilibrium model of the Canadian economy to assess the distributional impact of a GHG mitigation policy using the carbon tax as a policy instrument. We choose equivalent income as the household's welfare metric. As equivalent income depends on both commodity and factor prices, we are able to assess the contribution of both supply- and demand-side channels alluded to above in evaluating the impact of our chosen GHG control policy on inequality. We use the concentration ratio to assess and explain the changes in inequality by components following the implementation

as the household welfare metric and stress the importance of the distributional impact by analyzing inequality through a decomposition method of those elements considered important in income and spending decisions of households.

[4]They argue that the contribution assigned to any income source is sensitive to the way in which other sources are grouped.

[5]They suggested the solutions of performance overlapping among many simultaneously implemented poverty reductions programs by introducing average measures of the marginal contribution of each program based on all the possible permutations of the various policies implemented by the government

of the carbon mitigation policy.

2 Theoretical Background

This section presents a very simple model that will be useful for providing a good grasp of the impact of pollution taxes on factor prices. In particular, we assess the impact of a pollution tax on the relative price of capital and labor. The model will later help in building intuition on the distributional impact of carbon taxes on households. As argued before, a general equilibrium setting is the most appropriate framework for capturing the impact of a pollution tax on factor prices. The minimal representation of the environment required for this purpose consists of two firms, two production factors, and one household. The rationale for the sufficiency of one representative household at this stage rests on our assumption that households have Gorman preferences, whereby, without loss of generality, a representative consumer's preferences can be used to compute household demand.

In what follows in this section, we consider a closed economy that consists of two firms, one representative household and the government whose role is very basic. Each firm produces one good indexed by i= (1, the clean good, and, 2, the dirty good) by combining capital and labor with a constant-returns-to-scale technology. For the moment, we assume that no intermediate inputs are used in production activities.[6] The supplies of capital and labor are fixed and they are owned by the representative household. The latter has homothetic preferences over the two goods and derives income from the ownership of the primary factors and from tax revenue. Pollution is assumed to stem for the use of the dirty good alone according to a fixed proportion rule. As there are no intermediate inputs, pollution emanates from the consumption of the dirty good. The government has a simple role: its objective is to reduce pollution by imposing a tax on the consumption of the dirty good. For the sake of simplicity, and without loss of generality, we assume that the pollution tax is an ad valorem tax, t, that is imposed on the value of the dirty good. Alternatively, the pollution tax can be represented by the gross tax, $\tau = (1 + t)$. The proceeds of the taxes are returned to households. Finally, all agents operate in a competitive environment.

To achieve our objective, we will first characterize the consumer's and firms' behaviors and assess, in a general equilibrium setting, the impact of the pollution tax on the relative producer prices of the two goods as well as its impact on relative factor prices. As in most general equilibrium models, we are interested in the changes in relative prices; hence, our discussions below will mostly focus on the price and volume ratios instead of their levels.

2.1 The Consumer Problem

We assume that consumer preferences can be represented by a twice-continuously differentiable utility function. Let P_1 and P_2 be the producer prices of X_1 and X_2,

[6] We relax that assumption in a more broader and computable version of the model.

which represent the demands for goods 1 and 2 by the consumer. As consumer preferences are homothetic, at the optimum, the ratio of the demand for the two goods $\frac{X_2}{X_1}$ is independent of the level of income; it depends on the relative price only.

$$\frac{X_2}{X_1} = f\left(\frac{P_1}{\tau P_2}\right) \qquad with\ f' > 0 \tag{1}$$

By log-differentiation of Equation (1) we have:

$$\partial \ln\left(\frac{X_1}{X_2}\right) = -\sigma_d\left[\partial \ln\left[\frac{P_1}{P_2}\right] - \partial \ln \tau\right] \tag{2}$$

where σ_d is the elasticity of substitution between the two goods, which is a local measure of the curvature of their indifference curve. In Equation 2, an increase in the pollution tax, will reduce the ratio of the relative demand of the dirty good.

2.2 The Producer Problem

Each firm combines capital and labor to produce output, Q_i, using a constant-returns-to-scale technology that can be represented by a well-behaved twice-continuously differentiable cost function. The firm producing the dirty good is capital intensive, and we assume that there is no reversal in capital intensity, in the sense that the existing hierarchy in capital intensities holds for all vectors of positive input prices. Assuming that the two factors are fully used (equilibrium in both factor markets), the aggregate output in this economy is fixed. The combinations of the maximums of each good that can be produced is represented by a concave transformation curve. The concavity of the transformation curve stems from the assumptions of constant returns to scale technology and differing capital intensity ratios. As is well known, in a competitive environment, at a given ratio of output prices, the optimal supply of the two goods is such that the marginal rate of transformation is equal to the price ratio. In particular, the ratio of output depends on the ratio of output prices:

$$\frac{Q_1}{Q_2} = g\left(\frac{P_1}{P_2}\right) \qquad with\ g' > 0 \tag{3}$$

By log differentiation of Equation (3) we have:

$$\partial \ln\left(\frac{Q_1}{Q_2}\right) = \sigma_s \partial \ln\left(\frac{P_1}{P_2}\right) \qquad with\ \sigma_s > 0 \tag{4}$$

The parameter σ_s is the elasticity of substitution in supply between the two goods. The σ_s depends on the elasticities of substitution between capital and labor, the capital intensities in both firms, and on the shares of each input used in each firm. Its positive sign has bearing with the concavity of the transformation curve. Assuming equilibrium in the output markets, Equation (4) can thus be rewritten as follows:

$$\ln\left(\frac{X_1}{X_2}\right) = \sigma_s \partial \ln\left(\frac{P_1}{P_2}\right) \tag{5}$$

We thus have two equations, Equations 2 and 5, that can be used to assess the impact of the change in the pollution tax, τ on the relative price of the two goods. Hence our first proposition:

Proposition 1. *If the dirty and clean goods are substitutes in demand, under the assumptions that both firms use linear homogenous technologies and that the production of the dirty good is capital intensive, an increase in the pollution tax will increase the relative producer price of the clean good.*

Proof: The proof of Proposition 1 is straightforward. Combining Equations 2 and 5, it can easily be shown that:

$$\frac{\partial \ln\left(\frac{P_1}{P_2}\right)}{\partial \ln \tau} = \frac{\sigma_d}{\sigma_d + \sigma_s} \tag{6}$$

From Equation 2 the relative price of the clean good is positively related to the pollution tax when the elasticity of substitution in demand is positive.[7] The intuition behind this result is that an increase in the pollution tax increases the relative demand of the clean good that can only be achieved in equilibrium if the relative supply increases as well. Given the shape of the transformation curve, this can only occur with an increase in the relative price of the clean good. We are now left with the impact of the pollution tax on the relative factor prices.

With constant-returns-to-scale technology, the cost function, $C_i(w, r, Q_i)$, is linear in output and has the following general expression:

$$C_i(w, r, Q_i) = \min_{K_i, L_i} \{rK_i + wL_i : F_i(K_i, L_i) \geq Q_i\} \tag{7}$$

where w, r, and C_i respectively, the wage rate, the rental rate of capital, and the unit cost of production and $F_i(K_i, L_i)$ is a well-behaved production function.

$$C_i(w, r, Q_i) = Q_i c_i(w, r) \tag{8}$$

At the optimum, each firm sets its price equal to its marginal cost and determines the optimal level of input through cost minimization. The first order conditions of their optimization problem are as follows.

$$P_i = c_i(w, r) \tag{9a}$$

$$L_i = \frac{\partial ci(w, r)}{\partial w} Q_i = a_{Li} Q_i \tag{9b}$$

$$Ki = \frac{\partial ci(w, r)}{\partial r} Q_i = a_{Ki} Q_i \tag{9c}$$

[7] From our assumption on the technology of the two goods, σ_s is always positive

Equation (9a) reflects the marginal cost pricing rule and Equations (9b-9c) are the conditional factor demands for labor and capital, respectively. a_{Li} and a_{Ki} are, respectively the quantities of labor and capital required to produce one unit of output i. Let us continue to apply the smokestack concept according to which the emission-intensive sector is also capital-intensive. Hence, the assumption that the ratio of capital to labor is higher in Firm 2 than the one in Firm 1, implies that $a_{K2}/a_{L2} > a_{K1}/a_{L1}$ or equivalently, $a_{K2}/a_{K1} > a_{L2}/a_{L1}$.

It is easy to show through total differentiation of Equation (9) that the following relations exist between the percentages changes in output and factor prices

$$\partial \ln(P_1) = \theta_{L1} \partial \ln(w) + (1 - \theta_{L1}) \partial \ln(r) \tag{10a}$$

$$\partial ln(P_2) = \theta_{L2} \partial \ln(w) + (1 - \theta_{L2}) \partial \ln(r) \tag{10b}$$

where θ_{Li} is the share of labor in the cost of good i; it can also be shown that $\theta_{Li} = a_{Li} w / P_i$.

This system of two equations with two unknowns ($\partial \ln(w)$ and $\partial \ln(r)$) has a unique solution if and only if its determinant is different from zero. Yet, it can easily be shown that the determinant, which is equal to $(\theta_{L1} - \theta_{L2})$ is indeed different from zero for all vectors of input prices, with the assumptions of different capital intensities in the two firms and no capital intensity reversal.
The solution to the system of equations yields:

$$\partial \ln(w) = (1 - \theta_{L2}) \partial \ln P_1 - (1 - \theta_{L1}) \partial \ln P_2 \tag{11a}$$

$$\partial \ln(r) = \theta_{L1} \partial \ln P_2 - \theta_{L2} \partial \ln P_1 \tag{11b}$$

We thus have the following proposition with regards to the impact of pollution tax on the relative price of factors:

Proposition 2. *If the dirty and clean goods are substitutes in demand, the dirty good is capital intensive, and both firms use linear homogenous technologies, an increase in the pollution tax decreases the relative price of capital.*

Proof The proof of this proposition is straightforward.

$$\frac{\partial \ln(w) - \partial \ln(r)}{\partial \ln(\tau)} = \frac{\partial \ln(w) - \partial \ln(r)}{\partial \ln(P_1) - \partial \ln(P2)} \frac{\partial \ln(P_1) - \partial \ln(P2)}{\partial \ln(\tau)} \tag{12}$$

Using equations (6,11a,11b), we have:

$$\frac{\partial \ln(w) - \partial \ln(r)}{\partial \ln(\tau)} = \frac{1}{\theta_{L1} - \theta_{L2}} \frac{\sigma_d}{\sigma_d + \sigma_s} \tag{13}$$

The right-hand side of expression (13) has a positive sign since the ratio of labor to capital is higher in the firm that produces the clean good than in the other. The intuition behind this result follows from the one discussed in the previous proposition and the Stolper-Samuelson theorem. The latter suggests that there is a positive relationship between the relative price of a good and the relative price of the factor used intensively in the production of that good.

2.3 Incidence on Equivalent Income

To explain the inequality and welfare consequences of pollution tax on income distribution, we apply the equivalent incomes approach as suggested by King (1983).[8] Assume that the reference or pre-policy budget constraint of a household is denoted as (P^0, M_h^0) where P is the vector of the household's consumption prices and M_h is its income. Throughout this section, the superscripts 0 and 1 represent the pre- and post-policy status of a variable, respectively. The equivalent incomes (total expenditure) can be defined as the value of total expenditure, M_h^E, that at the reference prices , leaves the household at the same level of utility as that obtained under the current or post-policy budget constraint (P^1, M_h^1):

$$v(P^0, M_h^E) = v(P^1, M_h^1) \tag{14}$$

We assume that the household has a Cobb-Douglas utility function, which it maximizes subject to a budget constraint.

$$\begin{aligned} \max_{X_1, X_2} U &= X_1^{\beta} X_2^{1-\beta} \\ \textit{subject to } M_h &\geq P_1 X_1 + P_2 X_2 \quad \textit{and} \quad \textit{with } 0 < \beta < 1 \end{aligned} \tag{15}$$

For a given vector of prices and income, the indirect utility function of household h has the following expression:

$$v(P, M_h) = \left(\frac{\beta}{P_1}\right)^{\beta} \left(\frac{1-\beta}{P_2}\right)^{1-\beta} \tag{16}$$

Considering Equations (14) and (16), we may write the following relationship between equivalent incomes and the household income after the reform:

$$M_h^E = M_h^1 \left(\frac{P_1^1}{P_1^0}\right)^{-\beta} \left(\frac{P_2^1}{P_2^0}\right)^{\beta-1} \tag{17}$$

The first-order approximation of Equation (17) can be rewritten in terms of the percentage changes in the variables (logarithmic derivatives) on its Right-hand-side after the reform.

$$M_h^E = M_h^0 (1 + \partial \ln M_h) \left[1 - \beta \partial \ln P_1 - (1-\beta) \partial \ln P_2 + \xi\right] \tag{18}$$

where ξ is the combined effect of the commodity price changes.

[8] An alternative measure of capturing welfare is living standard. For more detail, see Shorrocks (2004).

Assuming that the consumer's total income M_h consists of labor and capital incomes, the percentage change in his total income can be derived as follows:

$$M_h = w\overline{L}_h + r\overline{K}_h \quad (19)$$

$$\partial \ln M_h = \theta_{Lh}\partial \ln w + \theta_{Kh}\partial \ln r \quad (20)$$

where $\overline{L}_h$ and $\overline{K}_h$ are, respectively, the consumer endowments of labour and capital, and θ_{Lh}, and θ_{Kh} represent, respectively the shares of labour and capital in total income.

Combining Equations (18 and 19), the equivalent incomes, M_h^E, can be decomposed as follows:

$$M_h^E = M_h^0(1 + \theta_{Lh}\partial \ln w + \theta_{Kh}\partial \ln r)\left[1 - \beta\partial \ln P_1 - (1-\beta)\partial \ln P_2 + \xi\right] \quad (21)$$

$$M_h^E = M_h^0 + M_h^0(\theta_{Lh}\partial \ln w + \theta_{Kh}\partial \ln r) - \beta M_h^0\partial \ln P_1 - (1-\beta)M_h^0\partial \ln P_2 + \xi_h \quad (22)$$

$$M_h^E = M_h^0 + \delta_h^1 + \delta_h^2 + \delta_h^3 + \delta_h^4 \quad (23)$$

where

$$\delta_h^1 = M_h^0(\theta_{Lh}\partial \ln w + \theta_{Kh}\partial \ln r) \quad (24)$$

$$\delta_h^2 = -\beta M_h^0\partial \ln P_1 \quad (25)$$

$$\delta_h^3 = -M_h^0(1-\beta)\partial \ln P_2 \quad (26)$$

$$\delta_h^4 = M_h^E - (M_h^0 + \delta_h^1 + \delta_h^2 + \delta_h^3) \quad (27)$$

Equation (23) suggests that the equivalent incomes after the reform can be decomposed into five components: (i) the equivalent incomes before the reform, M_h^0; (ii) the impact of the change in factor prices, δ_h^1; (iii) the impact of the change in the price of the clean good, δ_h^2; (iv) the impact of the change in the price of the dirty good δ_h^3; and (v) the residual that captures the combined impacts of changes in factor prices and in commodity prices, δ_h^4. Since the main focus of our analysis is to evaluate the contribution of each component to the change in the post-policy income inequality among households, we can reformulate Equation 23 as:

$$d_h \equiv \triangle M_h = \sum_{n=1}^{4} \delta_h^n \quad (28)$$

Where d_h, which refers to the post reform variation in the total equivalent incomes of the household of category h. It is worthy to mention, however, that the impact of an individual component in the variation of equivalent incomes may be positive or negative, depending on the post-reform changes in factor and commodity prices. For example, Equation 24 implies that the post policy decline in factor prices accounts for a fall in the equivalent incomes of the household through this component. A similar intuition can be extracted through Equation 26 if the post reform commodity prices of dirty goods increase as compare to their business as usual price levels. On the other hand, Equation 25 implies the post-policy decline in non-energy prices, as compare to the pre-policy levels, causes an increase in the equivalent incomes of the household by this component. The overall incidence of the pollution tax policy on the household's equivalent incomes is negative if the net impact of all component is negative. We will come back to a detail analysis of the post reform impact of each component on total equivalent incomes of the household in section 5.

2.4 Income Inequality and Decomposition Rule

Consider a population equally distributed among H household groups. Households are ranked according to the post-policy variations in their equivalent incomes (total expenditures) such that $d_1 \leq d_2 \leq ... \leq d_H$. In addition, δ_h^n $(n = 1, 2, 3, 4)$ is the n^{th} source of variation in equivalent income of household h which can be aggregated for H households in order to obtain its mean by component, $\mu(n) = \frac{1}{H}\sum_{h=1}^{H} \delta_h^n$, which allows us to estimate the mean of total variation in equivalent incomes as $\mu(d) = \sum_n \mu(n)$. Following Pyatt et al. (1980), we can write the Gini coefficient for the post-policy variations in equivalent incomes as the sum of the weighted average of concentration ratios of each component of variation with respect to total variations as:

$$G(d) = \sum_n S^n C^n \tag{29}$$

where $S^n(= \mu(n)/\mu(d))$ is the share of n^{th} component in total variation in equivalent income. C^n is a concentration ratio which measures the association of each component's variation with respect to the rank or cumulative distribution of a variation in equivalent incomes:

$$C^n = \frac{2COV[\delta^n, r(d)]}{\mu(n)} \tag{30}$$

Here $r(d)$ is the cumulative distribution of the total variation in equivalent income. With some simple manipulations, we can show that:

$$C^n = \frac{2COV[\delta^n, r(\delta^n)]}{\mu(n)} * \frac{COV[\delta^n, r(d)]}{COV[\delta^n, r(\delta^n)]} = G^n R^n \tag{31}$$

Here G^n is the relative Gini of component n^{th}, and R^n is the Gini correlation between the n^{th} component and the cumulative distribution of the total variation in equivalent income.[9] Since $r(\delta^n)$ is a non-decreasing function of δ^n, $COV[\delta^n, r(\delta^n)] \geq 0$ and $G^n \geq 0$. On the other hand, $COV[\delta^n, r(d)]$ could either be positive or negative, as is also the case with C^n, depending on whether the variation through a component is an increasing or a decreasing function of the rank $r(d)$. If there is no source of variation by component, then $C^n = 0$, meaning

[9] Plugging equation 30 into 31 would give a similar formulation as explained by Lerman and Yitzhaki (1985) i.e., $G = \sum_n S^n G^n R^n$ where the product SGR shows the contribution of n^{th} component in Gini coefficient for an *ex post* variation in total income.

that the component has no contribution in the post-policy variation in equivalent incomes.C^n could also be greater than one if some values of a component variable are negative. To see the contribution of each component of income variation to post-policy income inequality among household groups, we can re-adjust Equation 29 as:

$$\sum_{n=1}^{4} S^n[C^n - G(d)] = 0 \tag{32}$$

If a component of variation in equivalent incomes is more closely associated with the rank of total income losses relative to the variation in total income,[10] then $C^n > G(d)$, which suggests that the n^{th} component is more concentrated towards the higher rank of distribution; in our case this is the higher income group. Hence, the incidence of such policy on equivalent income through the n^{th} source would be progressive. Conversely, it would be regressive.

3 The Numerical Model

We develop a small open, static, multisector, and multi-household general equilibrium model to assess the distributional impact of a carbon tax in light of the theoretical discussions presented in the section above. A noticeable departure of this numerical model, from the analysis we presented above is that, not only do we have more than two commodities, but we also consider an open economy that trades goods and services with the rest of the world. The model is in the tradition of computable general equilibrium models used to assess climate change policy options in several countries. In particular, it has bearing with some recent interesting contributions to the literature on the general equilibrium modelling of climate change in a multisector and static setting, such as that of Araar et al.(2011) and Böhringer and Rutherford (2010). A noteworthy difference in the model discussed here from that presented in the above-mentioned reference is that instead of using a single representative household, we consider several categories of households that are distinguished by their total income category. In addition to households, the economy consists of firms, the government and the rest of the world. The economy is disaggregated into 39 industries, indexed by j, and 43 commodities indexed by i. The number of commodities is larger than that of industries, because some industries, like the oil and gas industry produce more than one commodity (crude oil and natural gas in their case).[11]

We assume that the use of fossil fuels generates carbon dioxide (CO_2) whose level the government desires to regulate using a carbon tax as a policy instrument. All agents consider prices as given and must respect their budget constraints. It is worth mentioning that in addition to the impact of the tax on the consumption good as explained in our theoretical discussions, we also have a direct impact of

[10] Alternatively, we can say that $COV[\delta^n, r(d)] > COV[d, r(d)]$.

[11] See section 4 for details of industries and commodities.

the tax on fossil fuels that are used as intermediate inputs. Hence, the carbon tax will also have a direct impact on the producer prices of non-fossil-fuel goods. The extent of the producer price increase of the latter goods will depend on their carbon content. Finally, capital and labour are assumed to be mobile across industries.

In order to avoid the black-box syndrome related to CGE models, in what follows, we provide the key features of the behavioral aspects of the economic agents as well as the resource constraints they face. We believe that a discussion of these features will allow the reader to understand the intuition behind the numerical results of the model. Readers interested in more details on the algebraic derivations of the equations in the present model, are requested to consult the above-mentioned paper.[12]

3.1 Households

We disaggregate the household sector into 100 categories, indexed by h, according to a quantile ranking that is based on the total income of each household category. The preferences of the representative household of each category over the 43 commodities is represented by a Cobb-Douglas (C-D) utility function[13]. The household is assumed not to value leisure, hence, its labour supply, L_h^s, is inelastic. It follows that there is a fixed endowment of total labour supply available in the economy. In the same vein, each household category has a fixed endowment, K_h, of the total supply of the capital stock in the economy. The household derives income from wages, capital income, transfers from the government, and net transfers from the rest of the world. It pays taxes on income and consumption goods and saves a fixed fraction of its disposable income. The representative household's problem is to choose its optimal combination of consumption goods by maximizing its utility function subject to the budget constraint:

$$\max_{C_i} \prod_{i=1}^{n} C_{hi}^{\beta_{hi}} \quad with \quad \sum_i \beta_{hi} = 1$$

subject to

$$\sum_i P_i^c C_{hi} \leq (1 - t_{fh})(wL_h^s + RK_h) + TR_h^G - eTR_h^{fr} - S_h \equiv M_h \qquad (33)$$

where M_h, P_i^c, C_{hi}, are respectively, total expenditures, the price and the demand for the consumption good; t_{fh}, is the household income tax rate; w, is the wage rate; and, L_h^s is the household's labour supply. RK_h is the return to capital received by each household from the firms, while, TR_h^G, TR_h^{fr}, S_h, and e are respectively, transfers from the government, net transfers from the rest of the world (in world

[12] The detail of the nesting structure and model Algebra is available from the authors.

[13] In the remainder of the text, we may use (for the sake of simplicity), the word household to designate the representative household of each category.

prices), savings, and the nominal exchange rate.[14] β_{hi} is a parameter of the utility function. As will be discussed below, the consumption good is a composite of the domestically produced and imported goods, and its price incorporates the effects of the carbon taxes that have been imposed on the uses of the intermediate inputs during its production.

It is straightforward to show that the demand for each commodity by each household has the following expression:

$$P_i^c C_{hi} = \beta_{hi} M_h \tag{34}$$

As saving is a fixed fraction of disposable income, it can be expressed as follows:

$$S_h = s_h \left[(1 - t_{fh})(wL_h^s + RK_h) + TR_h^G - eTR_h^{fr} \right] \tag{35}$$

Finally, the return to capital received by each household, RK_h, is a fixed proportion, β_h^K, of total dividend payments received from the firms. It is important to note that the sum of the dividends paid is lower than the total remuneration of capital in the economy, as firms keep a fixed proportion, β^{KE} for investment purposes. Hence RK_h has the following expression:

$$RK_h = \beta_h^K (1 - \beta^{KE}) \sum_j r K_j^d \tag{36}$$

where r, and K_j^d, are, respectively, the rental rate of capital, and the sectoral demand for capital by each industry.

3.2 Production

The representative firm in each industry has access to a linear homogeneous production function to produce a composite good that can be sold in the domestic and exports markets. The production technology is assumed to be weakly separable, uses capital, labour, fossil inputs and non-fossil inputs to produce the gross output. The weak separability property of the technology is captured by the nested structure of production as depicted in Figure 1. An interesting property of this separability is that it makes it possible to account for the substitution possibilities that are offered to the firms, as far as the use of energy products is concerned. This distinction is all the more important in the context of a pollution tax that is based on the carbon content of the fuel used.

As shown in Figure (1), at the top level of the production structure, the composite of output is a Constant Elasticity of Substitution (CES) of the aggregate of the composite of value-added and energy, KEL_j, and of the composite of intermediate inputs V_j. At the second level, the composite KEL_j is a Cobb-Douglas aggregate of labour, L_j^d, and a composite of capital and energy KE_j. At the third

[14] It is important to note that without income tax and saving, the total expenditures, M_h, will be identical to the concept of total income that we used in our analysis of the decomposition of household equivalent incomes in the previous section.

level of the nesting structure, the sectoral capital stock K_j is combined with the composite of energy inputs, E_j through a CES aggregation function to produce KE_j. The composite of energy input is a CES function of electricity and an aggregate of fossil fuels. The latter is another CES combination of coal, natural gas, and the composite of refined petroleum products. The composite of intermediate inputs is a CES function of a composite of a C-D aggregate of motive fuels and a Leontief aggregate of the other material inputs.

An overview of the production structure is depicted in Figure 1[15]

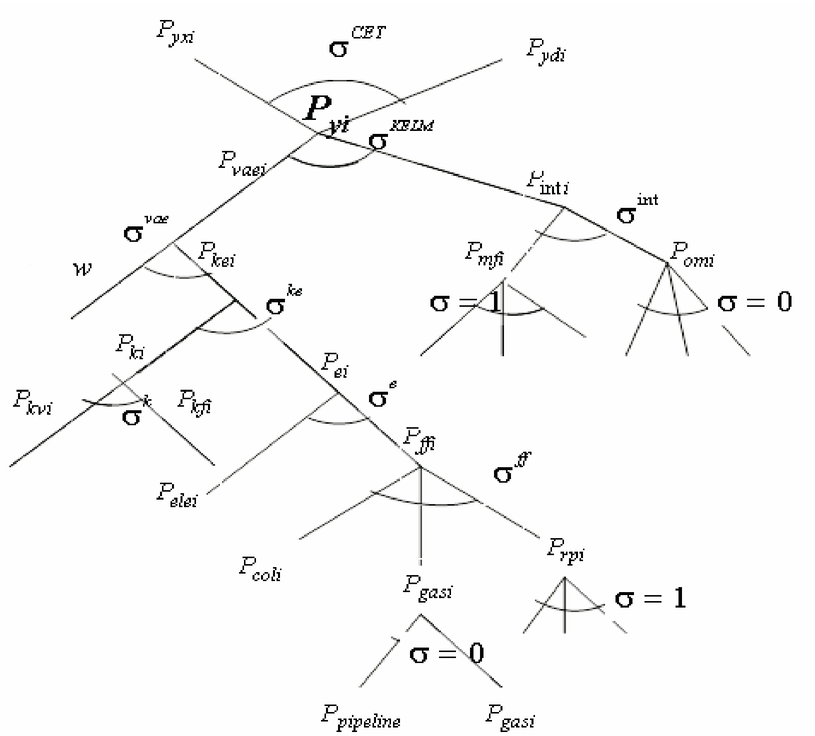


Figure 1: An overview of Production Structure of Sectors

The representative firm pays taxes net of subsidies on gross output and maximizes profits in order to determine the optimal levels of inputs. The traditional principle of equalizing the marginal product of the input to its price applies in this setting. Note that the price of a composite input is its dual price, which is obtained through a cost-minimization principle. An increase in the carbon tax will not only reduce the demand for the fossil fuel, but will also trigger a cascading increase in the dual prices of composite inputs and will eventually lead to an increase in the producer price of the composite good.

As mentioned above, the representative firm produces a composite good that is made of the domestic good and the export good. Both are imperfect substitutes and their production technology is captured by a concave transformation

[15]The detail of the nesting structure and model Algebra is available from the authors.

curve. Notably, a Constant Elasticity of Transformation (CET) function is used to transform the gross output into sales in domestic market and exports. The representative firm uses a revenue-maximizing principle subject to the technological constraint (represented by the transformation curve) to determine the optimal allocation of the gross output into sales in the two markets. For example, at the optimum, everything else equal, the increase in the relative price of exports will reduce the ratio of domestic sales to those in foreign markets.

Finally, the representative firm returns a fixed proportion, β^{KE}, of the return to physical capital to households as dividend payment, pays business income taxes and uses the remainder for investment purposes.

3.3 Government, Equilibrium Conditions and Closure Rules

The government collects direct and indirect taxes from households, firms, and international trade activities, including pollution activities. The government also provides subsidies and makes transfers to households. It is compelled to balance its budget constraint. The general equilibrium of this economy is represented by a vector of price and quantity variables such that all agents maximize their objective functions while respecting their respective budget constraints, and all markets clear. In equilibrium, the following conditions should be met: i) zero profit or no arbitrage conditions by all representative firms ii) income balance conditions, in which the household's income must be equal to its expenditure and government revenue must be equal to its expenditure iii) markets clearing conditions, which implies equilibrium in the labour market, capital market, domestic goods market, and foreign exchange markets.

The model is real in the sense that changes in nominal variables do not have any impact on the real variables; only relative prices matter. The exchange rate is taken as a numeraire. In addition, the model considers Canada as a small open economy, which takes the prices of imports and exports as well as foreign savings as exogenous.

Carbon emissions embodied in each commodity are represented by an emissions coefficient, which is the ratio of total emissions associated with a commodity divided by the total consumption of this commodity by all households and firms. The multiplication of the emissions coefficients of each commodity by the commodity demands by all households and firms gives us the share of that commodity in total emissions. Assume that $Emit_i$ is an emissions factor (i.e., the quantity of CO_2, in tons, which emits in the burning of fossil fuels), P^q is the unit price of carbon, denoted in \$ per ton of CO_2, and $\overline{P}_i^c$ is the composite price of domestic and imported good . The post-policy price of a polluted good will, therefore, be $P_i^c = \overline{P}_i^c + P^q Emit_i$. At a given price of carbon, the equilibrium level of cap of emissions from commodity i is determined endogenously.

4 Data Structure and CGE Results

To simulate the baseline case, we construct a social accounting matrix (SAM), which is based on the Canadian national accounts of 2004. The SAM contains 39 industries and 43 commodities. For analytical reasons, we categorize all industries either into energy-related or non energy-related sectors. *Energy-related industries* (EJ) include fossil fuels (contain coal, oil, and gas), gas pipeline, refineries (comprise gasoline, diesel, liquefied petroleum, other refineries), and electricity. *Non-Energy related industries* (NEJ) encompass Energy-Intensive (EIS) industries (contain pulp-paper, printing, chemical, mining, plastic & rubber, non metallic metals, steel and other metals, machinery, transport services) and Non-Energy-Intensive (NEIS) industries (contain agriculture, food, construction, textile, wood, transport equipment, other manufacturing, wholesale, retail trade, communication, education, health, accommodation, electric products, storage, fire, business service, and other services). The inventory values of carbon dioxide (CO2) emissions are taken from Statistics Canada. As indicated in the previous section, we align emissions inventory with economic data by calculating the emissions factor of each commodity.

We obtain household information from the "Social Policy Simulation Database" (SPSD), which is a database that comprises a transformation of four data sources into a single non-confidential and publicly used micro data file. The SPSD process uses the Survey of Labour and Income Dynamics (SLID) as a host dataset and then maps it with the donor datasets (i.e., Personal Income Tax Return data, Employment Insurance (EI), and the Survey of Household Spending) based on some similar records or categorical matchings among different datasets.[16] The database produces 82,753 observations of households for the base year 2004. These observations are then sorted by the value of total expenditures of each household. Finally, the sorted sample is equally distributed among 100 household groups. In order to integrate the household data into our CGE model, the income and expenditure records of the 100 quantiles are also aligned with the records available in the national Input-Output account.

The model is numerically run using the GAMS software with the CONOPT solver. The business-as usual (BAU) case refers to a calibration with no carbon tax policy. The analytical structure of the model enables it to calibrate the equilibrium prices and quantities of goods, which are very consistent with the actual data. Table 1 depicts the database values of Gross Domestic Product (GDP) and its components, CO2 emissions, total earnings of all households from capital and labour services. In fact, the baseline[17] model calibrates precisely the same values of selected indicators depicted in Table 1.

[16] A detail of categorical matching is explained in the "Database Creation Guide" of SPSD/M package of Statistics Canada.

[17] Throughout this paper, we interchangeably use the words "BAU" and "baseline" for no carbon tax policy case

Table 1: Baseline Calibration of Real Aggregate Economic Indicators(In Trillion $CN)

Indicators	Database Value
GDP at Market Price	1.288
Consumption	0.720
Investment	0.267
Exports	0.495
Imports	0.441
Government Expenditure	0.249
CO2 Emissions(MT)	588
Households Total Capital Income	0.138
Households Total Labour Income	0.705

4.1 Counterfactual Analysis

The model can examine the counterfactual scenarios by imposing different values for the carbon tax. However in this section, we illustrate the impacts of a $15, $30, $50, and $100 carbon tax on the economy as a whole, and on its individual sectors.

4.1.1 Aggregate Impact

The aggregate impact of the imposed carbon taxes in the economy is represented by the variation in real GDP relative to the level of BAU. As expected, the post-policy[18] real GDP declines ranging from 0.11% to an almost 1% (see Table 2). To investigate the aggregate impact of a carbon tax more precisely, we decompose the incidence on real GDP by its components and by categories of commodities, which we discussed in section 4.

The real consumption is the most effected component of real GDP showing a decline in total final consumptions ranging from 0.28% to 1.32% when the carbon tax increases from $ 15 to $100. As anticipated, the major decline in real consumption is due to the fall in demands for energy goods. This is because of the substitution effect, which represents a change in the composition of final demand due to a change in relative prices. Table 2 shows that the policy induced distortion in relative price of energy goods is higher, the higher is the carbon tax. The falls in demands for energy goods cause no investment growth in energy sectors. However, the real investment, at aggregate level, increases by 0.17% at $15 to 0.41% at $100 tax, mainly due to the high investment activities in non-Energy-Intensive sectors.

The post reform changes in trade activities also show some interesting results. For example, Table 2 shows that the energy-intensive industries face the compet-

[18]Throughout this paper we interchangeably use the words *post-policy* and *post-reform*.

itiveness issues from their foreign competitors. The exports of energy-intensive products decline by 0.4% at $15 to 1.5% at $100 tax, while the imports of the similar products increase by 0.1$ at $15 to 0.3% at $100 tax. On the other hand the exports of non-energy intensive products increase ranging from 0.3% to 1.4%, with no changes in the imports of similar products relative to the BAU level.

It is also interesting to note that the relative factor prices (i.e., the ratio of the rental rate of capital to the wage rate) decline monotonically ranging from -0.93% to -4.34% as the value of the carbon tax increases from $15 to $100. Intuitively, this aligns with the smokestack concept (see Hettige et al (1992)), which illustrates that the energy intensive goods are relatively capital intensive. Hence on the income-side, the incidence of a carbon tax is likely to be higher across those households that derive a higher share of their income through capital earning. We will discuss, in detail, the distributional aspect arising from the income-side channel in the next section.

Table 2 also shows that the composite price of all commodities, on average, increases monotonically with the increase in the carbon tax (from 0.3% at $15 to 2.3% at $100) indicating that the relative commodity prices would be stronger at relatively higher carbon tax levels. Therefore, on the consumption-side, the incidence of a carbon tax will reduce the purchasing power of households—those households having a higher share of their earned income on the consumption of the goods will be more negatively affected due to the higher relative levels of commodity prices. We will return to discussing the distributional aspect emerging from the demand-side channel in more detail in section 5.

4.1.2 Sectoral Impact

The carbon tax can affect the economy's sectors through at least two channels—direct and indirect. The direct channel refers to an increase in the cost of fossil-fuel energy in the production process. The extent of this increase depends on the carbon content of the fossil fuel used and its share in the production cost. This effect further transmits to the downstream sectors, which use emissions-intensive goods as intermediate inputs. The cost of production could vary depending on the content of emissions embodied in energy related intermediate goods. A potential indirect channel through which the carbon tax affects the economy is represented by the substitution possibilities among energy sources, as well as between energy and non-energy inputs. The ultimate effects of these two channels have a bearing on the supply and the demand for each commodity, which determine the qualitative impact of a carbon tax policy on sectoral prices. Let us explain the above direct and indirect sectoral effects more explicitly through our empirical results.

By grouping industries into three sets of sectors, namely the fossil fuel sector, the non-fossil fuel energy-intensive sector, and the non energy-intensive sector, one can easily explain the policy impacts through the different channels stated above. For example, the fossil-fuel producing industries experience a significant increase in their post-policy cost of production. This direct effect causes a rise in the user prices (following the imposition of a carbon tax) of these sectors. In response, the demands for their products considerably decline (see Table 3 and Table 4). The fall in the demand for fossil fuel forces these sectors to reduce their producer prices. Hence, the producer price of oil and gas, for instance, falls below its BAU level. Nevertheless, because of its high emissions intensity, the coal industry experiences an increase in its production cost and its producer price increases despite the fall in the demand for its product.

The indirect effects are mainly represented by the substitution of high energy-intensive goods to low energy-intensive ones. Households substitute away from fossil fuel energy to the relatively less expensive energy, which in our case is electricity (See Table 3). Even the substitution possibility among energy sources may not help the downstream industries (such as chemical, steel and other metals, non-metallic metals, pulp-papers-printing, and transport services) to reasonably reduce their post-policy cost of production. They also experience increases in their post-policy user prices (See Table 3). Similar to fossil fuel industries, the post-policy commodity/user prices of downstream energy intensive sectors also depend on their sector specific demand and supply forces. For example, steel and other metal, pulp, paper, and printing, and transport service reflect a supply-side driven increase in their ex-post commodity price, meaning that the fall in the supply of their commodities makes their commodity or user prices higher than producer prices (see Table 3). On the other hand, chemical and non-metallic metals sectors face demand-side driven commodity price changes as these sectors show higher ex-post producer prices than the policy-induced commodity (or user) prices.

The indirect channel also reveals that the substitution effect between energy-intensive and non energy-intensive sectors causes a fall in the demands for energy-intensive goods, which in turn, leads to a reduction in the demand for the factors used in the production of these commodities (see Table 5). Hence, we see in Table 5 that the post-policy demands for capital and labour, in almost all of the energy-intensive sectors, falls. In most of the energy and energy-intensive sectors, the incidence of the carbon tax on factor incomes is negative. In contrast, the demands for some non-energy intensive commodities such as construction, textile and wood, plastic and rubber, machinery, transport equipment, and communication increase (see Table 4). Consequently, the demand for capital and labour, in these industries increases relative to the BAU case (see Table 5). However, due to the low factor price, household earning from these sectors may not overcome the loss in household income brought about by a contraction in energy and energy-intensive sectors. Similar to fossil fuel and energy-intensive industries, the post-policy commodity/user prices of non-energy-intensive sectors, also depend on their sector specific demand and supply forces. For example, the post-policy prices of the goods such as food, transport equipment, textile and wood products, wholesale and retail trade are demand-induced because the producer prices of these commodities exceed their ex-post user prices. On the other hand, industries such as machinery, other manufacturing, health, and communication reflect the supply-side impact as revealed by their post-policy user prices.

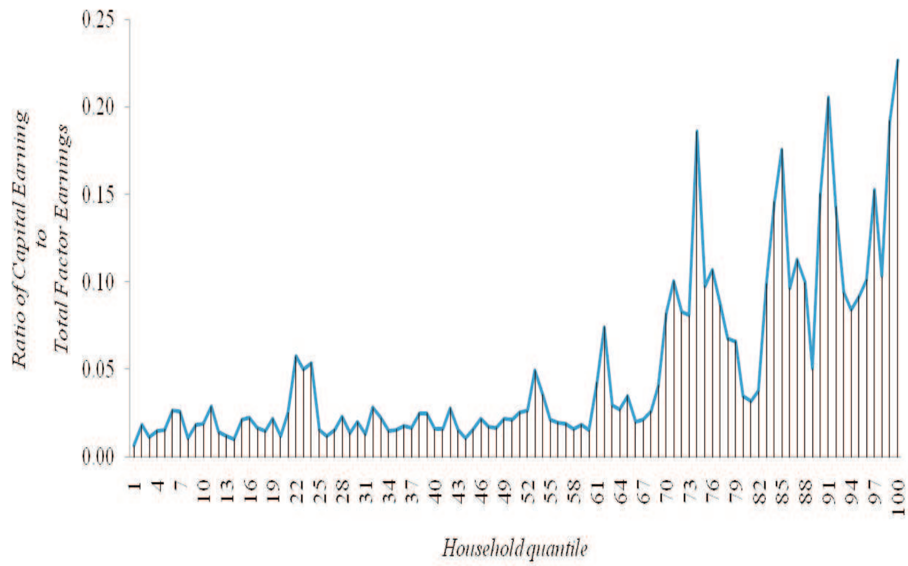


Figure 2: Ratio of Capital Earning to Equivalent Incomes among Different Household Groups

5 Distributional Impact

To assess the distributional impact of a carbon tax policy, we calibrate the baseline model by decomposing household sector into 100-quantile groups. It is interesting to first review the pre-policy contribution of each factor of equivalent incomes (expenditures) in the household's income and consumption patterns. For example, Figure 2, suggests that in the base run, the share of capital earnings to equivalent incomes is higher for rich households in comparison to poor households. In contrast, the share of energy consumption in total expenditures is higher for the latter category of households than for the rich households (see Figure 3). As expected, the distribution of each component, among household groups, is skewed even in the BAU case.

Figures 2 and 3 support our argument that the incidence of a carbon tax policy on households will have opposite impacts through two sides, i.e., the source vs. the use side. On the source-side, the negative impact of the underlying policy would be relatively larger for the higher income groups because the capital earning is more heavily affected than the labour income. On the use-side, the policy would negatively affect low income quantiles because energy goods become more expensive than non-energy goods. Let us examine these two sides of policy incidence through some counterfactual analysis.

Tables 6-8 show the impacts of a carbon tax valued at \$30, \$50, and \$100, respectively on the household's equivalent incomes by its components across 20 quantile income groups. Notice that the percentage loss in total equivalent incomes, relative to the base case, is larger among upper quantile groups, which becomes more effected when the value of the carbon taxes increases from \$30 to \$100 (see

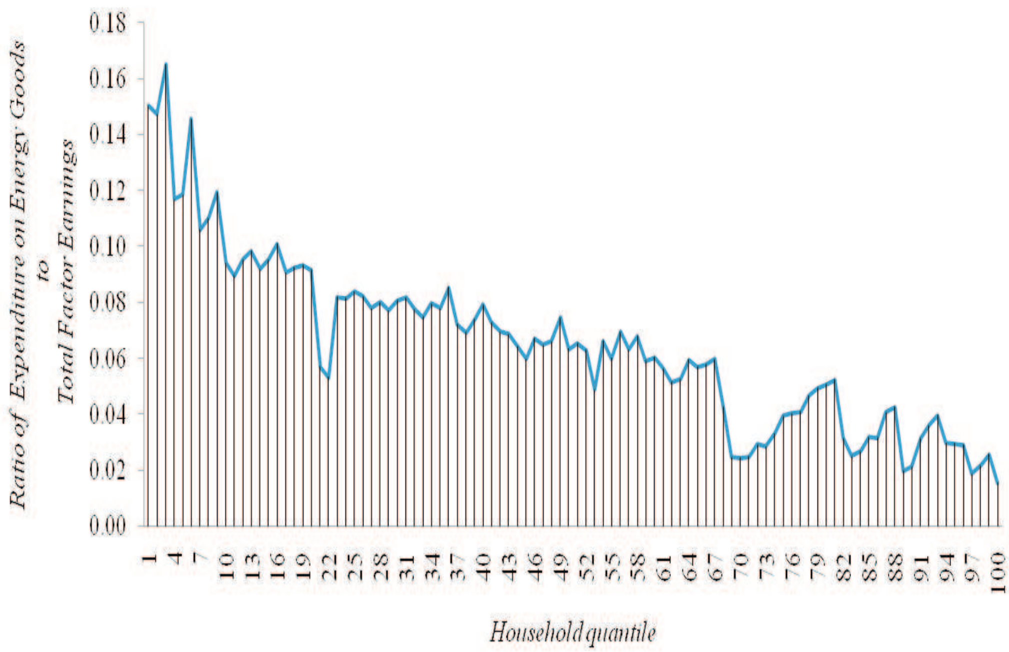


Figure 3: Ratio of Expenditure in Energy Goods to Equivalent Incomes among Different Household Groups

column two of Tables 6-8). The intuition can be deduced from the decomposition of total loss in equivalent income by its components.

On the source-side (i.e., through the variation in relative factor prices), one can assess the incidence of the carbon tax on equivalent income by calculating the ratio of decline in capital to wage earnings mentioned in Tables 6-8, which shows that the losses in households' income through capital earnings are considerably high among the higher income groups, causing these groups be more affected by the pollution tax policy relative to the lower income groups. Figure 4 shows that the losses in capital to wage earnings are higher among high income groups compared to low income groups. This is consistent with the results we inferred above in the BAU case (see Figure 2).

Similarly on the use-side (i.e., through the variation in relative commodity prices), we can assess the incidence of the carbon tax by calculating the ratio of the changes in energy and non-energy consumptions to the total variations in factors earnings among income quantile groups. For instance, Figure 5 shows that the incidence of the carbon tax through increase in energy prices is larger across the low income groups relative to the high income groups. This is also consistent with the results we inferred in the baseline case (see Figure 3). Figure 5 also shows that the variation in equivalent incomes through energy price changes is four times larger than the variation in equivalent incomes through factor earnings among the low income groups, indicating that the use-side effect is more influential within this income group. As well, the extent of the impact of the carbon tax on the low

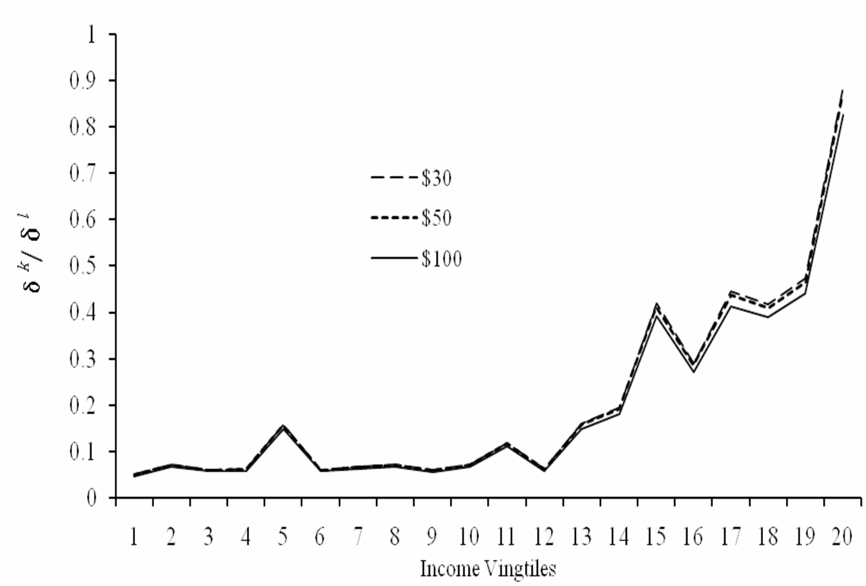


Figure 4: Ratio of losses in Capital to Labour Earnings in total Losses in Equivalent Incomes.

income group is sensitive to the size of the carbon tax (see Figure 5).

Notice that the last two columns in Tables 6-8 show that the incidence of the carbon tax through the change in non-energy goods prices and other components, as explained earlier, is positive. Moreover, Figure 6 shows that the positive impacts on equivalent incomes through the changes in non-energy goods prices and other components are large enough to offset the negative impact on equivalent incomes through declines in factor prices among the low and middle income groups. Yet, these income groups need to also face the negative impact on equivalent incomes brought about by the increase in energy prices. In contrast, among high income groups, the positive impact of changes in non-energy prices and other components is not sufficient to completely offset the negative impacts due to declines in their factor earnings.

5.1 Income Inequality

In the previous sections, we discussed the potential channels through which the incidence of the carbon tax can be transmitted to an economy at the aggregate, sectoral, and household levels. These discussions provide reasonable support to our argument that the incidence of a carbon tax across household groups has opposing effects when analyzed through the consumption and income sides, provided that i) energy intensive sectors are capital intensive, ii) high income households own a higher share of capital earnings in their total earned incomes relative to the low income groups and, iii) low income households spend more of their earned incomes on energy related goods. To investigate the distributional impact of an environmental tax more precisely, we estimate the Gini indices of the post-policy

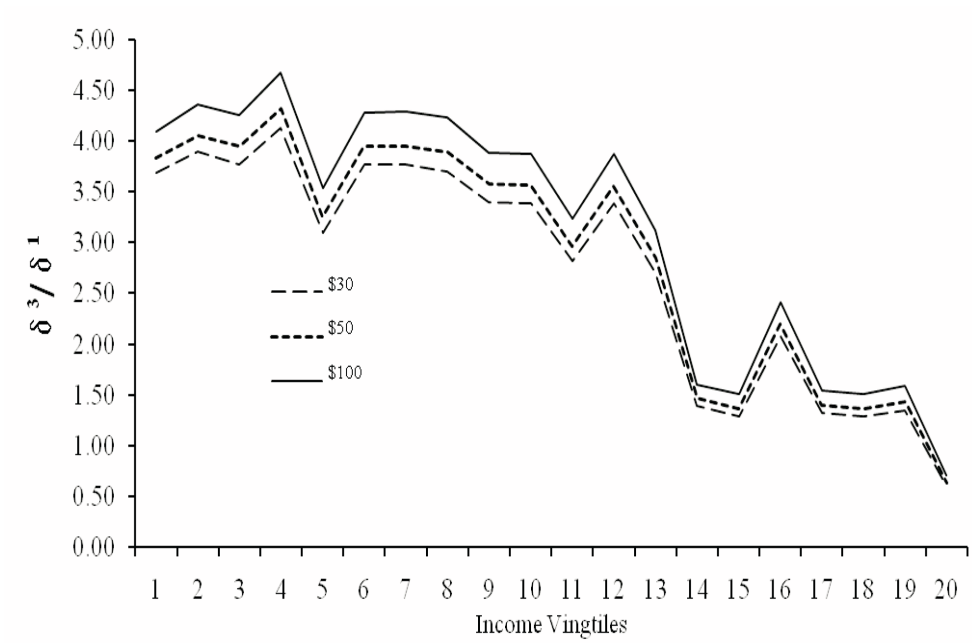


Figure 5: Ratio of Decline in Energy Consumptions to the Declines in Total Factors Incomes.

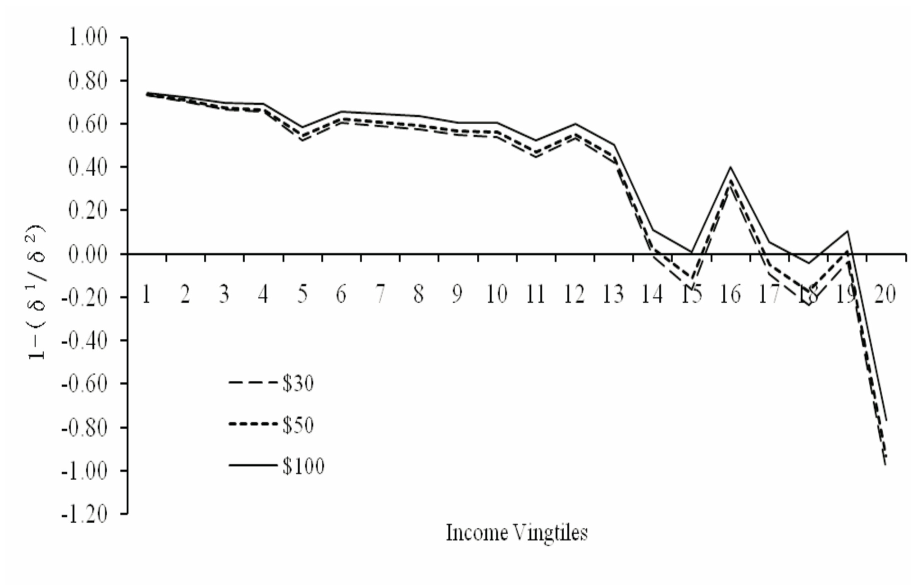


Figure 6: The Contribution of Non-energy Prices and Others Components to Offset the Loss of Households' Total Equivalent Incomes through the Variations in Factors Prices.

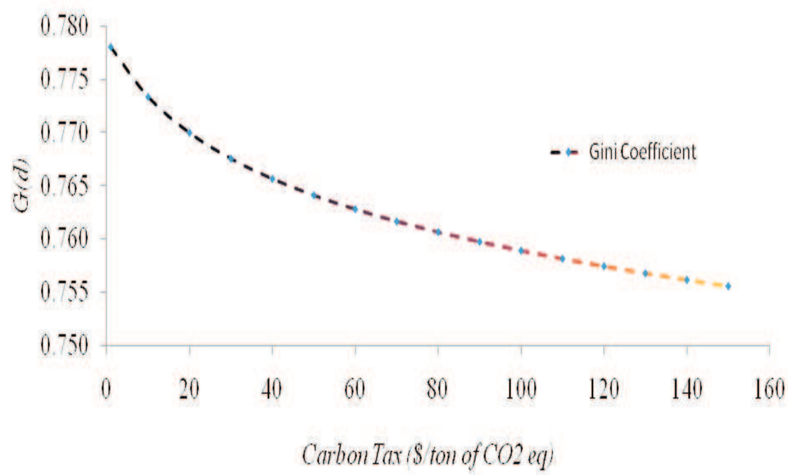
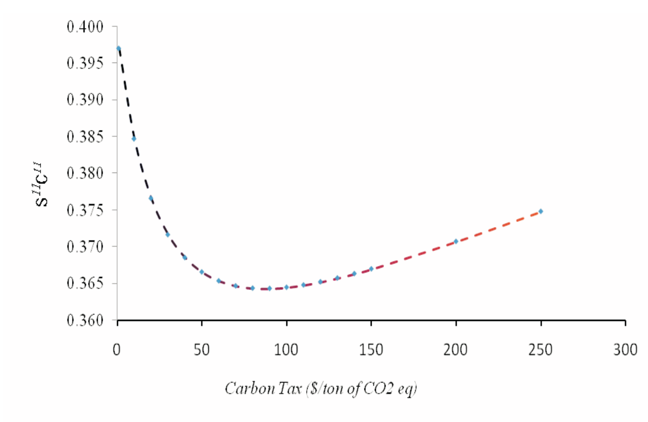
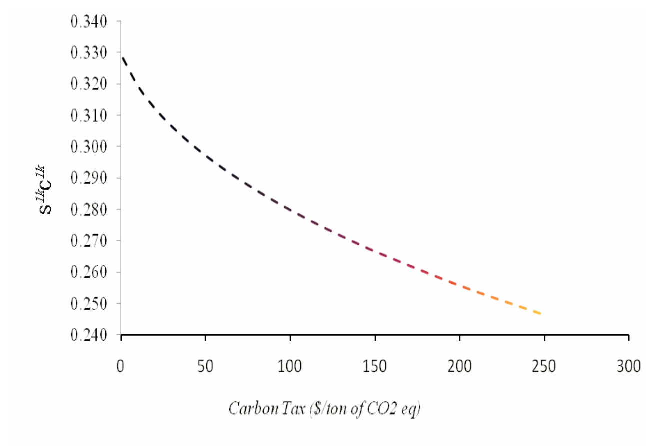


Figure 7: Income Inequality at Different Carbon Prices

variation in equivalent incomes by their income and expenditure components.



(a) Income Inequality by variation in Labour Income



(b) Income Inequality by variation in Capital Income

Figure 8: Income Inequality by Income Components

As is discussed earlier in Tables 6-8, when the price of carbon increases from $30 to $100, the loss in the total equivalent incomes, relative to the BAU level, is more concentrated towards the high income groups. Figure 7 also shows a similar result for a range of carbon prices, with the highest price being $150. As demonstrated by Table 9, the Gini coefficient declines as the price of the carbon tax increases from zero to $150. This implies that the overall impact of carbon prices on household equivalent incomes is progressive. The decomposition of the total Gini into its different components (as discussed in Equation 29) is also shown in Table 9.

As expected, a loss in factor income explains the monotonic decline in the Gini coefficient when carbon prices increase from zero to $150. However, the incidence of the carbon tax on labour income of households varies, depending upon the level of the tax rate. The Gini coefficient via this component, is progressive up to a $90 carbon tax (see Table 9), indicating that the loss of labour income is distributed more towards the high income groups. However, beyond a $90 value of the carbon tax, the incidence of the tax through this factor takes on a modest regressive effect (see Figure 8). In contrast, the incidence of the tax on capital earning is progressive at any tax level (see Figure 8) possibly because, as shown in Figure 2, the earnings from this source accumulate more toward the higher income groups. It can be calculated from Table 9 that the ratio, $\frac{S^{1k}C^{1k}}{S^{1l}C^{1l}}$, declines when the carbon tax exceeds $10, indicating that the marginal impact of carbon tax incidence on equivalent incomes through capital earning is high relative to that of labour income.[19]

On the other hand, a change in the composite of energy prices, at different levels of the carbon tax, accounts for an increase in the Gini coefficient. Hence, the incidence of carbon tax through this component is regressive as it affects more heavily the low income household group. This is consistent with our results in Figure 3, which shows that the low income groups spend a higher proportion of their earned income on energy related goods.[20] A post-policy increase in energy prices would cause an increase in the demand for a substituted non-energy good, as long as the post-policy user prices of substitute goods are relatively low. Hence, the purchasing power of households to buy those goods increases. An interesting point to note is that the Gini coefficient from this source also increases when we move from a low to a high carbon price, implying that the overall impact of a change in commodity prices is more concentrated towards the lower income group as carbon prices increase. This result is mostly discussed in the distributional related literature although through the use of different household welfare measures (see for example, Metcalf (2009) and Wier et al. (2005)). However, due to the stronger incidence of factor income, the combined effects of factor and commodity prices tend to reduce inequality following an increase in the carbon tax.

Table 10 also shows that the income losses through factor earnings concentrate towards the rich hosueholds as the price of carbon increases, implying that the incidence of the pollution tax on the source-side of income is progressive. A similar result is obtained for the combined effect. Conversely, the incidence of pollution

[19]In a related paper, Oladosu and Rose (2007), also find a similar result that the incidence of carbon tax is mildly progressive while they use cost-side income distribution for in the Susquehanna River Basin regions of the USA. They estimated the incidence by using income bracket changes, per capita equivalent variation, and Gini coefficient changes based on consumption pattern. However their methodology is different from us; they have not discussed the contribution of individual cost-side factor in the tax incidence. In other related papers, Metcalf et al. (2010) and Rausch et al. (2009) also find that the distributional impact of $15 CO2eq tax on households is progressive while considering a combination of use and source sides. Our methodology differs from them as we explicitly show role of each component of equivalent incones affecting households' income and consumption patterns.

[20]As we explained earlier, we consider household's earned income in Figure 3 rather than their total consumption so as to avoid the impact of any transfer.

tax on the use-side (i.e., through commodity price changes) of income is regressive.

6 Conclusions

In this paper, we have investigated the incidence of pollution control policies on households' income while incorporating equivalent incomes as the household welfare metric and concentration indices as the decomposition method of illustrating inequality by components. The strength of equivalent incomes, for this analysis, rests on their incorporation of both commodity and factor prices, while the concentration ratio approach allows for an assessment of the contribution of each component of equivalent incomes to total inequality. The main focus of this paper has been to develop a methodology to disentangle the components of the source and use sides of households' equivalent incomes and to examine the continuation of individual factors in the total incidence of a pollution tax policy.

We have developed a multi-sector, multi-household general equilibrium model of the Canadian economy to assess the distributional impact of a GHG mitigation policy in Canada by using a carbon tax as the policy instrument. The simulation results are then used to calculate the concentration indices of the components of equivalent incomes. In calibrating the model to different carbon tax levels, our CGE results suggest strong impacts of pollution control policies on relative factors and commodity prices. On the income-side, a carbon tax reduces both the wage rate and the rental rate on capital. However, the capital earnings are more heavily affected than the wages as the ratio of the rental rate of capital to the wage rate declines monotonically when we switch from a low (e.g., \$15) to a high (e.g., \$100) carbon tax. On the use-side, a carbon tax reduces the consumer prices of non energy-intensive goods, while it increases the consumer prices of energy-intensive goods relative to their BAU levels. However, due to a strong impact on energy prices, the composite price of all commodities, on average, is monotonically increased with an increase in the carbon tax.

The CGE results have also addressed the impacts of post-policy variations in factor and commodity prices across 100 household groups. The results show that the post-policy decline in relative factor prices have higher negative impacts on upper quintile groups because they derive a larger share of their income from capital earnings source in comparison to lower quintile groups. On the other hand, the impact of a change in energy prices seems to have a relatively stronger effect on low income groups than the higher income groups as the former spend more of their total expenditure on energy related goods than the latter.

Finally, we have analyzed the issue of income distribution by using the Gini index as an inequality measure. Our estimation shows that the Gini values of variations in equivalent incomes decline as carbon prices increase, implying that the overall impact of a pollution tax on household's equivalent incomes is progressive.

We have decomposed total inequality by components of factor and commodity prices. Our estimates show that the incidence of a pollution tax on relative factor prices accounts for a decline in the Gini coefficient, while its incidence on relative commodity prices accounts for an increase in the Gini coefficient. In further decomposing the incidence on the above-mentioned relative prices, we find some interesting results.

On the income side, the inequality through wage earnings represents a U-shaped curve, as it changes from a progressive to a mild regressive impact when the carbon tax levied exceeds a certain level, which in our numerical example is $90. On the other hand, the inequality through capital earnings declines monotonically with an increase in the carbon tax. The overall impact through relative factor prices, nonetheless, is progressive.

On the expenditure side, the incidence of energy prices on household distribution is regressive. An interesting point is that the inequality through non-energy prices is also regressive as it increases when we move from a low to a high carbon price, implying that the overall impact of a change in commodity prices is more concentrated among the lower income group in the presence of increasing carbon prices.

However, due to a stronger incidence from factor prices, the joint effects of factor and commodity prices cause the overall impact of carbon prices on household's equivalent incomes to be progressive. These findings suggest that the traditional approach of assessing the impact of carbon taxes on inequality through changes in commodity prices alone may be misleading.

Certainly, there are avenues to undertake further research within the decomposition framework we discussed in this paper. There are several social, demographic, and economic factors, which can be incorporated into this study. For example, the labour income can be categorized into different occupation groups or skilled/unskilled categories. One can also introduce alternative policies of emissions and revenue allocations, as discussed by Rausch et al. (2009), within our analytical framework.

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Table 2: Aggregate Impacts of Different Values of Carbon Tax ($ Per Ton of CO_2)

	$15	$30	$50	$100
% Change Relative to Base Case				
∘*Real GDP at Market Price*	-0.11	-0.24	-0.43	-0.91
A. Real Consumption	-0.28	-0.51	-0.78	-1.32
i. Energy Goods(EJ)	-0.21	-0.37	-0.55	-0.88
ii. Non-Energy Goods(NEJ)	-0.07	-0.14	-0.22	-0.44
a. Energy-Intensive Goods(EIS)	-0.04	-0.07	-0.12	-0.20
b. Non-Energy-Intensive Goods(NEIS)	-0.03	-0.06	-0.11	-0.24
B. Real Investment	0.17	0.27	0.35	0.41
i. Energy Goods(EJ)	0.00	0.00	0.00	0.01
ii. Non-Energy Goods(NEJ)	0.17	0.27	0.35	0.40
a. Energy-Intensive Goods(EIS)	0.03	0.05	0.07	0.10
b. Non-Energy-Intensive Goods(NEIS)	0.14	0.22	0.27	0.30
C. Real Exports	-0.16	-0.26	-0.35	-0.49
i. Energy Goods(EJ)	-0.11	-0.19	-0.28	-0.42
ii. Non-Energy Goods(NEJ)	-0.05	-0.07	-0.07	-0.07
a. Energy-Intensive Goods(EIS)	-0.37	-0.64	-0.94	-1.49
b. Non-Energy-Intensive Goods(NEIS)	0.31	0.58	0.87	1.42
D. Real Imports	-0.16	-0.26	-0.35	-0.49
i. Energy Goods(EJ)	-0.24	-0.41	-0.57	-0.85
ii. Non-Energy Goods(NEJ)	0.08	0.15	0.23	0.36
a. Energy-Intensive Goods(EIS)	0.07	0.13	0.20	0.34
b. Non-Energy-Intensive Goods(NEIS)	0.01	0.02	0.02	0.02
∘*Rental rate of capital*	-1.28	-2.37	-3.61	-6.10
∘*Nominal wage rate*	-0.36	-0.66	-1.03	-1.84
∘*Ratio of rental rate of capital to wage rate*	-0.93	-1.71	-2.61	-4.34
∘*Consumer Price Index*	0.30	0.63	1.10	2.31
∘*Consumer Price Index (Non − Energy Goods)*	-0.05	-0.07	-0.09	-0.07
∘*Consumer Price Index (Energy Goods)*	17.20	34.42	57.40	115.04
∘*Reduction in Total Emissions*	-14.51	-23.31	-31.59	-44.75

Table 3: Impacts of Carbon Taxes on Different Prices

Sectors	$30			$50			$100		
	Value-Added Price	Producer Price	User Price*	Value-Added Price	Producer Price	User Price*	Value-Added Price	Producer Price	User Price*
	Percentage Change from Base case								
Energy									
Electricity	-0.38	4.32	4.41	-0.49	6.25	6.38	-0.63	10.01	10.18
Oil and gas	-0.13	-1.02	11.97	-0.19	-1.82	19.97	-0.32	-2.49	39.97
Coal	-0.11	0.07	166.14	-0.16	0.17	276.94	-0.27	0.48	554.00
Refineries	-0.08	0.57	23.40	-0.12	0.90	39.31	-0.20	1.53	79.90
Non-energy									
Agriculture	-0.10	0.02	0.02	-0.15	0.10	0.10	-0.25	0.40	0.41
Food	-0.10	-0.20	-0.21	-0.15	-0.25	-0.27	-0.25	-0.25	-0.27
Construction	-0.16	0.79	0.79	-0.24	1.30	1.30	-0.38	2.51	2.51
Textile & Wood	-0.09	-0.30	-0.42	-0.13	-0.42	-0.59	-0.21	-0.62	-0.85
Pulp, Paper & Printing	-0.09	0.25	0.45	-0.14	0.43	0.74	-0.22	0.89	1.45
Chemical	-0.11	2.59	1.97	-0.16	4.12	3.06	-0.28	7.40	5.22
Mining	-0.11	0.09	0.14	-0.38	-0.17	0.33	-0.37	0.66	0.95
Plastic & Rubber	-0.08	0.18	0.20	-0.12	0.29	0.33	-0.28	0.52	0.58
Non Metallic Metals	-0.11	0.41	0.36	-0.16	0.68	0.60	-0.26	1.36	1.20
Steel and other metals	-0.15	1.08	1.17	-0.21	1.56	1.68	-0.32	2.53	2.63
Machinery	-0.12	-0.11	-0.07	-0.18	-0.18	-0.12	-0.30	-0.30	-0.20
Transport Equipment	-0.12	-0.22	-0.25	-0.18	-0.33	-0.38	-0.29	-0.55	-0.64
Other Manufacturing	-0.15	-0.10	-0.06	-0.22	-0.13	-0.08	-0.35	-0.14	-0.09
Wholesale	-0.12	-0.41	-0.46	-0.18	-0.59	-0.66	-0.29	-0.89	-1.00
Retail Trade	-0.07	-0.54	-0.54	-0.11	-0.81	-0.82	-0.18	-1.36	-1.36
Transport Services	-0.11	1.19	1.44	-0.17	1.94	2.33	-0.28	3.62	4.30
Communication	-0.12	-0.92	-0.91	-0.18	-1.39	-1.38	-0.29	-2.33	-2.31
Education	-0.08	-0.46	-0.48	-0.13	-0.68	-0.72	-0.22	-1.13	-1.20
Health	-0.08	-0.70	-0.69	-0.12	-1.07	-1.06	-0.20	-1.83	-1.81
Accommodation	-0.07	-0.54	-0.53	-0.10	-0.81	-0.79	-0.17	-1.33	-1.30
All Others	-0.10	-0.44	-0.47	-0.15	-0.64	-0.69	-0.25	-1.02	-1.09

* Including carbon tax

Table 4: Impacts of Carbon Tax on Commodities Demand, Supply and Prices

Sectors	$30			$50			$100		
	Total Supply	Total Demand	Domestic Price	Total Supply	Total Demand	Domestic Price	Total Supply	Total Demand	Domestic Price
	Percentage Change from Base case								
Energy									
Electricity	-4.54	-3.74	4.58	-6.31	-5.20	6.63	-9.35	-7.69	10.59
Natural gas	-4.85	-11.61	-2.94	-7.60	-17.93	-4.61	-12.60	-30.16	-8.27
Coal	-54.56	-55.32	0.17	-65.61	-66.25	0.42	-77.96	-78.21	1.20
Gasoline	-14.34	-13.30	1.77	-21.23	-19.95	2.54	-33.36	-32.12	3.64
Other fuels for vehicles	-16.43	-16.57	-0.06	-22.15	-24.39	-0.16	-34.44	-37.85	-0.51
Non-energy commodities									
Agriculture	-0.07	-0.05	0.02	-0.36	-0.30	0.12	-1.43	-1.17	0.48
Food	-0.10	-0.35	-0.27	-0.32	-0.63	-0.34	-1.08	-1.38	-0.33
Construction	0.64	0.65	0.79	0.68	0.68	1.31	0.26	0.27	2.51
Textile & Wood	1.48	0.23	-0.67	2.01	0.20	-0.95	2.63	-0.11	-1.41
Pulp, Paper & Printing	-2.30	-1.06	0.67	-3.68	-1.69	1.12	-6.68	-3.07	2.20
Chemical	-12.50	-4.00	4.69	-18.54	-5.98	7.38	-29.08	-9.61	12.98
Mining	-6.48	-6.06	0.19	-9.55	-8.42	0.46	-15.95	-12.68	1.33
Plastic & Rubber	-0.21	0.65	0.40	-0.46	0.97	0.66	-1.13	1.49	1.20
Non Metallic Metals	-0.33	0.20	0.52	-0.69	0.18	0.86	-1.88	-0.14	1.72
Steel and other metals	-4.26	-0.24	2.21	-5.80	-0.18	3.19	-8.56	-0.08	5.07
Machinery	1.87	0.66	-0.39	2.86	0.90	-0.63	4.58	1.18	-1.07
Transport Equipment	4.80	2.05	-0.90	7.46	3.14	-1.38	12.68	5.16	-2.32
Other Manufacturing	0.39	-0.26	-0.24	0.41	-0.45	-0.32	0.06	-0.92	-0.36
Wholesale	0.10	-0.15	-0.50	0.08	-0.28	-0.71	-0.12	-0.66	-1.08
Retail Trade	-0.12	-0.14	-0.55	-0.22	-0.24	-0.82	-0.49	-0.54	-1.37
Transport Services	-2.54	-1.19	1.66	-4.00	-1.87	2.70	-7.11	-3.35	5.00
Communication	0.48	0.03	-1.02	0.69	0.01	-1.55	1.07	-0.10	-2.61
Education	-0.01	-0.18	-0.51	-0.06	-0.31	-0.77	-0.21	-0.63	-1.27
Health	-0.08	-0.09	-0.70	-0.13	-0.15	-1.07	-0.25	-0.30	-1.83
Accommodation	0.13	-0.31	-0.64	0.16	-0.50	-0.96	0.15	-0.94	-1.59
All Others	-0.32	-1.49	-0.74	-0.59	-2.30	-1.09	-1.22	-3.95	-1.75

Table 5: Impacts of Carbon Tax on Different Inputs of Productions

	$30			$50			$100		
	Capital	Labour	Energy	Capital	Labour	Energy	Capital	Labour	Energy
	Percentage Change from Base case								
Energy									
Electricity	-0.76	0.56	-30.90	-0.81	1.00	-40.44	-0.53	2.18	-53.98
Oil and gas	-3.47	-5.41	-21.49	-5.49	-8.38	-31.73	-9.08	-13.71	-49.11
Coal	-53.82	-54.32	-57.50	-64.75	-65.31	-69.03	-76.98	-77.57	-81.68
Refineries	-8.71	-13.30	-27.47	-13.01	-19.62	-38.98	-20.82	-30.68	-56.73
Non-energy									
Agriculture	1.29	0.30	-2.85	1.74	0.28	-4.64	2.22	-0.08	-8.71
Food	0.80	0.02	-3.49	1.06	-0.08	-5.61	1.21	-0.45	-10.34
Construction	0.62	2.49	-11.19	0.55	3.67	-17.41	-0.25	5.86	-29.61
Textile & Wood	2.44	1.53	-1.49	3.48	2.11	-2.60	5.11	2.95	-5.40
Pulp, Paper & Printing	-2.14	-1.55	-4.77	-3.45	-2.51	-0.01	-6.39	-4.56	-13.05
Chemical	-4.85	-8.61	-24.30	-7.12	-12.75	-7.45	-10.77	-19.89	-53.16
Mining	-5.00	-5.88	-13.15	-7.31	-8.57	-19.50	-12.25	-14.08	-31.71
Plastic & Rubber	1.38	0.08	-6.29	1.96	0.01	-9.60	2.90	-0.23	-16.26
Non Metallic Metals	0.08	0.70	-5.08	-0.08	0.93	-7.60	-0.93	1.15	-13.79
Steel and other metals	-3.88	-2.39	-10.61	-5.19	-3.13	-14.73	-7.50	-4.36	-22.00
Machinery	2.97	1.97	-2.47	4.54	3.05	-3.93	7.37	5.02	-7.35
Transport Equipment	5.88	4.84	0.56	9.13	7.54	0.72	15.58	12.97	0.46
Other Manufacturing	1.33	0.57	-5.12	1.83	0.73	-8.08	2.37	0.79	-14.31
Wholesale	1.35	0.09	-6.75	2.01	0.11	-10.51	3.16	0.08	-18.25
Retail Trade	0.97	-0.14	-3.52	1.44	-0.23	-5.42	2.28	-0.43	-9.50
Transport Services	-0.87	-1.85	-7.38	-1.47	-2.90	-11.32	-2.88	-5.10	-19.24
Communication	1.55	-0.06	-8.69	2.35	-0.11	-9.91	3.92	-0.22	-16.87
Education	0.81	0.14	-5.46	1.17	0.20	-8.51	1.72	0.31	-14.98
Health	1.22	-0.23	-4.56	1.86	-0.35	-6.95	3.11	-0.58	-11.83
Accommodation	1.34	0.13	-3.77	2.02	0.17	-5.73	3.31	0.23	-9.82
All Others	1.50	0.45	-4.31	2.26	0.67	-6.70	3.65	1.11	-11.69

Table 6: Variation in Equivalent Incomes by Components at $30 Carbon Tax (In % change Rel. to Base Case)

Vingtiles	% Decline in Total Equivalent Income rel. to Base-Case	% Change in Equivalent Incomes by Components				
		Factor Price		Commodity Price		Residual
		Wage Rate	Rental Rate	Energy Prices	Non-Energy Prices	
1	-0.17	-0.17	-0.01	-0.65	0.61	0.05
2	-0.29	-0.18	-0.01	-0.75	0.59	0.06
3	-0.38	-0.20	-0.01	-0.81	0.57	0.07
4	-0.48	-0.20	-0.01	-0.88	0.54	0.07
5	-0.59	-0.26	-0.04	-0.92	0.55	0.08
6	-0.54	-0.23	-0.01	-0.92	0.54	0.08
7	-0.58	-0.23	-0.02	-0.94	0.53	0.08
8	-0.61	-0.24	-0.02	-0.96	0.53	0.08
9	-0.60	-0.26	-0.02	-0.93	0.53	0.08
10	-0.61	-0.26	-0.02	-0.94	0.52	0.08
11	-0.66	-0.29	-0.04	-0.93	0.52	0.08
12	-0.63	-0.26	-0.02	-0.95	0.52	0.08
13	-0.68	-0.29	-0.05	-0.92	0.51	0.08
14	-0.80	-0.48	-0.09	-0.79	0.50	0.07
15	-0.95	-0.47	-0.20	-0.85	0.49	0.07
16	-0.63	-0.30	-0.09	-0.81	0.50	0.07
17	-0.84	-0.41	-0.18	-0.79	0.48	0.07
18	-1.00	-0.48	-0.20	-0.87	0.47	0.07
19	-0.80	-0.39	-0.18	-0.78	0.49	0.07
20	-1.17	-0.57	-0.50	-0.64	0.48	0.05

Table 7: Variation in Equivalent Income by Components at $50 Carbon Tax (In % change Rel. to Base Case)

Vingtiles	% Decline in Total Equivalent Income rel. to Base-Case	% Change in Equivalent Incomes by Components				
		Factor Price		Commodity Price		
		Wages	Rents	Energy Prices	Non-Energy Prices	Residual
1	-0.29	-0.26	-0.01	-1.05	0.91	0.13
2	-0.48	-0.28	-0.02	-1.21	0.88	0.15
3	-0.62	-0.31	-0.02	-1.31	0.86	0.16
4	-0.77	-0.31	-0.02	-1.43	0.81	0.18
5	-0.94	-0.40	-0.06	-1.49	0.81	0.19
6	-0.87	-0.36	-0.02	-1.49	0.81	0.19
7	-0.93	-0.36	-0.02	-1.53	0.79	0.20
8	-0.97	-0.37	-0.03	-1.56	0.79	0.20
9	-0.96	-0.40	-0.02	-1.51	0.78	0.20
10	-0.98	-0.40	-0.03	-1.53	0.78	0.20
11	-1.05	-0.46	-0.05	-1.51	0.77	0.20
12	-1.01	-0.41	-0.03	-1.55	0.77	0.20
13	-1.08	-0.46	-0.07	-1.51	0.76	0.20
14	-1.27	-0.74	-0.14	-1.29	0.74	0.17
15	-1.49	-0.72	-0.30	-1.39	0.74	0.18
16	-1.01	-0.47	-0.13	-1.32	0.74	0.17
17	-1.33	-0.64	-0.28	-1.29	0.71	0.17
18	-1.58	-0.74	-0.31	-1.43	0.70	0.19
19	-1.26	-0.61	-0.28	-1.27	0.73	0.17
20	-1.84	-0.88	-0.76	-1.05	0.71	0.14

Table 8: Variation in Equivalent Income by Components at $100 Carbon Tax (In % change Rel. to Base Case)

Vingtiles	% Decline in Total Equivalent Income rel. to Base-Case	% Change in Equivalent Incomes by Components: Factor Price: Wages	Factor Price: Rents	Commodity Price: Energy Prices	Commodity Price: Non-Energy Prices	Residual
1	-0.59	-0.46	-0.02	-1.99	1.48	0.42
2	-0.92	-0.50	-0.03	-2.31	1.43	0.49
3	-1.17	-0.56	-0.03	-2.51	1.39	0.54
4	-1.42	-0.55	-0.03	-2.74	1.31	0.60
5	-1.73	-0.71	-0.10	-2.87	1.32	0.63
6	-1.61	-0.64	-0.04	-2.88	1.32	0.63
7	-1.72	-0.65	-0.04	-2.96	1.29	0.65
8	-1.78	-0.67	-0.04	-3.01	1.28	0.66
9	-1.77	-0.71	-0.04	-2.93	1.27	0.65
10	-1.79	-0.71	-0.05	-2.95	1.26	0.65
11	-1.93	-0.81	-0.09	-2.92	1.25	0.65
12	-1.85	-0.73	-0.04	-3.00	1.26	0.67
13	-1.97	-0.82	-0.12	-2.92	1.24	0.65
14	-2.31	-1.32	-0.24	-2.50	1.20	0.55
15	-2.69	-1.29	-0.50	-2.70	1.19	0.61
16	-1.85	-0.84	-0.23	-2.56	1.20	0.57
17	-2.41	-1.14	-0.47	-2.50	1.15	0.56
18	-2.85	-1.33	-0.52	-2.77	1.14	0.63
19	-2.29	-1.08	-0.48	-2.47	1.18	0.56
20	-3.27	-1.56	-1.29	-2.04	1.16	0.46

Table 9: Decomposition of Gini by Components of Variations in Equivalent Incomes

Carbon Price	Inequality in Total Variation of Equivalent Incomes G(d)	Inequality by Components				
		Labour Wages $S^{1k}C^{1k}$	Capital Rents $S^{1l}C^{1l}$	Non-Energy Prices S^2C^2	Energy Prices S^3C^3	Residual S^4C^4
1	0.778	0.328	0.397	-0.358	0.412	-0.001
10	0.773	0.319	0.385	-0.338	0.421	-0.013
20	0.770	0.312	0.377	-0.323	0.430	-0.025
30	0.768	0.307	0.372	-0.312	0.439	-0.037
40	0.766	0.302	0.369	-0.303	0.447	-0.049
50	0.764	0.297	0.367	-0.295	0.455	-0.060
60	0.763	0.293	0.365	-0.288	0.464	-0.071
70	0.762	0.290	0.654	-0.282	0.471	-0.082
80	0.761	0.286	0.364	-0.277	0.479	-0.092
90	0.760	0.283	0.364	-0.272	0.486	-0.102
100	0.759	0.280	0.365	-0.267	0.494	-0.112
110	0.758	0.277	0.365	-0.263	0.501	-0.122
120	0.757	0.274	0.365	-0.259	0.508	-0.131
130	0.757	0.272	0.366	-0.255	0.515	-0.140
140	0.756	0.269	0.366	-0.252	0.522	-0.149
150	0.756	0.267	0.367	-0.249	0.528	-0.158

Table 10: Progressivity of Components at Different Carbon Prices

Carbon Price	Factor Prices $S^1[C^1 - G(d)]$	Non-Energy Prices $S^2[C^2 - G(d)]$	Energy Prices $S^3[C^3 - G(d)]$	Residual $S^4[C^4 - G(d)]$
1	0.05280	-0.15152	0.098259	0.000466
10	0.05528	-0.15002	0.090316	0.004429
20	0.05682	-0.14985	0.084544	0.008487
30	0.05776	-0.15039	0.080346	0.012280
40	0.05838	-0.15128	0.077042	0.015863
50	0.05880	-0.15238	0.074311	0.019270
60	0.05910	-0.1536	0.071978	0.022524
70	0.05931	-0.15489	0.069934	0.025645
80	0.05947	-0.15623	0.068113	0.028647
90	0.05958	-0.15759	0.066466	0.031543
100	0.05967	-0.15897	0.06496	0.034343
110	0.05973	-0.16036	0.063573	0.037054
120	0.05977	-0.16174	0.062284	0.039685
130	0.05980	-0.16312	0.061081	0.042242
140	0.05982	-0.16450	0.059952	0.044729
150	0.05982	-0.16586	0.058886	0.047153