C.I.R.P.É.E

Centre Interuniversitaire sur le Risque,
les Politiques Économiques et l'Emploi

Cahier de recherche/Working Paper **08-09**

Household Incidence of Pollution Control Policies : a Robust Welfare Analysis Using General Equilibrium Effects

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Juin/June 2008

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This research was partly funded by the IRND fund of the University of Ottawa, the PEP Programme of IDRC, by Canada's SSHRC, and by Québec's FQRSC. We thank Reza Ghazal for his very helpful research assistance, Randy Wigle for his helpful suggestions and seminar participants at Wilfrid Laurier University for their constructive comments. The usual caveats apply.

Abstract: This study assesses the incidence of pollution control policies on households. In contrast to previous studies, we employ an integrated framework combining a multisector general equilibrium model with a stochastic dominance analysis using household-level data. We consider three policy instruments in a domestic emission trading system: (i) an output-based allocation of permits (OBA); (ii) the use of the proceeds of permit sales to reduce payroll taxes (RPT); (iii) and the use of these proceeds to reduce consumption taxes instead (UCS). The general equilibrium results suggest that the return to capital is more negatively affected than the wage rate in all simulations, since polluting industries are capital intensive. Abstracting from pollution externalities, the dominance analysis allows us to conclude that all three policies have a normatively robust negative (positive) impact on welfare (poverty). Formal dominance tests indicate that RPT first-order welfare dominates OBA over all values of household incomes. UCS also first-order poverty dominates RPT for any choice of poverty line below $CAN 18,600, and poverty dominates for any poverty line (and thus welfare dominates) at the second order. Finally, while the three pollution control policies do not have a numerically large impact on inequality (in comparison to the base run), statistical tests indicate that inequality increases significantly more with OBA and RPT than with UCS.

Keywords: Pollution control policies, household incidence, stochastic dominance, general equilibrium effects

JEL Classification: C68, D31, D58, D63, H23, Q52, Q56

Résumé: Cet article évalue l’incidence des politiques de lutte contre la pollution sur le niveau de vie des ménages. Contrairement aux études précédentes, nous utilisons une approche intégrée combinant un modèle d’équilibre général multisectoriel avec une analyse de dominance stochastique basée sur des données de ménages. Nous considérons trois instruments de politique dans le cadre d’un système d’échange de droits d’émission : (i) une allocation de permis basée sur la production (OBA), (ii) l’utilisation du revenu de vente des permis pour réduire la taxe sur la masse salariale (RPT), (iii) et l’utilisation des revenus pour réduire la taxe sur la consommation (UCS). Les résultats du modèle d’équilibre général suggèrent que la rémunération du capital est plus affectée que le salaire dans toutes les simulations étant donnée la forte intensité capitalistique des industries polluantes. Abstraction faite des externalités créées par la pollution, l’analyse de dominance nous permet de conclure que les trois politiques ont, sur un plan normatif, de manière robuste un impact négatif (positif) sur le bien-être (la pauvreté). Les tests formels de dominance en bien-être indiquent que RPT domine au premier ordre OBA pour toutes les valeurs de revenus des ménages. UCS domine également au premier ordre RPT pour tout seuil de pauvreté inférieur à 18 600 $CAN, et au second ordre pour tout seuil de pauvreté. Enfin, alors que les trois politiques de lutte contre la pollution n’ont pas un impact important sur l’inégalité (en comparaison à la situation de référence), les tests statistiques indiquent que l’inégalité augmente davantage avec OBA et RPT qu’avec UCS.

1 Introduction

In recent years, much of the debate over the cost of pollution control policies has centered on their aggregate cost-effectiveness and not on their distributive welfare incidence. Yet, the distributive outcome of any policy that affects relative prices constitutes an important source of concern for policy makers. Concern for the incidence of the costs of green-house gas (GHG) abatement policies can be expressed from at least two perspectives: industries and households. With the first perspective, the concern is over the incidence of abatement costs across industries; with the second perspective, it is the policies' welfare incidence on households that is the main source of concern. The interest over the joint incidence of pollution control policies has been growing among researchers. A recent body of literature has begun to examine the distributive impact across industries of the cost of pollution control policies. Dissou (2006) and Goulder, Parry, Williams III, and Burtraw (1999) are just a few examples. The literature on the household incidence of environmental taxes is also increasingly abundant — see for instance Parry, Sigman, Walls, and Williams III (2005) for an interesting and extensive review of the literature.

Most studies suggest that environmental taxes tend to be regressive. The main reason for this is that lower income households usually spend a larger share of their income on energy goods than more affluent households; increasing taxes on energy goods is thus proportionately more harmful to poorer households. Many such studies use a partial equilibrium analysis in which it is assumed not only that energy taxes are fully passed through to consumers, but also that these taxes have no effects on the prices of other goods. West and Williams (2004) and Bento, Goulder, Henry, Jacobsen, and von Haefen (2005) are a few examples of studies using such a partial equilibrium approach.

Considering the significant share of energy goods in the production cost of other consumption goods, the above conclusion on the regressive nature of environmental taxes could certainly be qualified in a more general equilibrium setting. For example, Solow (1985) and Uri and Boyd (1997) find that when the indirect effects, *i.e.*, the spillover and feedback effects from other industries, of energy taxes, such as a thermal tax, are taken into consideration, energy taxes tend to be proportional — as opposed to being regressive when these effects are ignored. Accounting for the indirect effects of energy taxes on other goods through input-output tables, Casler and Rafiqui (1993) also find that these taxes are then only mildly regressive.

In a recent paper, Fullerton and Heutel (2007) discuss another channel through which environmental taxes can have a redistributive impact across households. As polluting industries tend to be relatively capital intensive, the use of market-based instruments to control emissions, under certain conditions on substitution elasticities, tends to reduce the relative return of capital to labor. Such a backward shift of a pollution tax on primary factors will then affect the distributive incidence of the tax since richer households generally derive a higher share of their income from capital.

The analysis of the incidence of environmental taxes can therefore be improved by considering the indirect effects of the taxes on the prices of other products and on factor returns. Existing general equilibrium analyses of the household incidence of environmental policy, such as Rose and Oladosu (2002) and Wiese and Schluter (1995), are nevertheless limited in their ability to show the distributive impacts of policies affecting relative prices. In contrast to partial equilibrium studies, which usually rely on detailed household-level survey data, existing general equilibrium studies indeed only include a rather limited number of representative households. Because of their aggregative nature, they are unable to take fully into account the considerable heterogeneity that can exist across households. The distributive changes suggested by these models only capture redistribution *between* groups, ignoring *intra-group* changes. The latter can only be accounted for fully using microeconomic household-level survey data.

This paper draws upon the strengths of both of the approaches described above by accounting for both general equilibrium effects and household-level heterogeneity in incomes and consumption. To do this, we use a two-step approach in which we first compute the general equilibrium effects on commodity prices and on primary factor returns, and then perform stochastic dominance analysis using household-level data.

A recurring insight derived of most studies on the economic cost of environmental policies is that the final outcome depends on the policy instrument used and on the method for recycling the revenue raised by these instruments. We thus consider three domestic emissions trading (DET) experiments: (i) a DET with an output-based allocation of permits (OBA); (ii) a DET with a recycling of permit proceeds to reduce payroll taxes (RPT); and (iii) a DET with a recycling of permit proceeds to reduce consumption taxes (UCS). While the last two types of DET are well known in the literature, the first is relatively new and is gaining popularity among policy makers in Europe and North America. An interesting characteristic of the OBA-DET is that it helps to even the distributive impact of pollution control policies across industries — see Dissou (2006), Bernard, Fischer, and Fox (2007) Goulder, Parry, Williams III, and Burtraw (1999) for an analysis of the cost- effectiveness of an OBA-DET scheme. We are not aware of any study that compares the household incidence of these types of emission trading.

We consider the Canadian economy, for which we elect to analyze the impact of a 15% reduction of GHG emissions from their business-as-usual (BAU) level using a cap-and-trade DET with different revenue-recycling methods. Note that this analysis does not have any link with official government policies to reduce GHG emissions in Canada. It is only done illustratively in order to derive some insights on the distributional impacts of alternative GHG mitigation policies using our suggested methodology.

For that purpose, the paper develops a multi-sector static general equilibrium model of the Canadian economy. This serves to provide the commodity and primary input price impacts of the three policy experiments described above. The commodity and primary input price changes obtained from the general equilibrium model are subsequently used in a stochastic dominance analysis using household-level data.

The dominance approach to assess the distributive and welfare implication of taxes is relatively well established in the public finance literature — see for instance Yitzhaki and Slemrod (1991), Mayshar and Yitzhaki (1995) and Duclos, Makdissi, and Wodon (forthcoming). Using stochastic dominance for analyzing the social welfare impact of policy has several advantages. The most important of these is to free the analysis from the need to make restrictive and arbitrary assumptions on the way in which social welfare is assessed. As we will see in greater details below, stochastic dominance can indeed be used to conclude that an environmental policy is good for society *regardless* of whether the normative focus is on poverty reduction or on social welfare improvement, of whether a particular social welfare function is used as opposed to another, and of whether one or another poverty line is chosen. In short, using the dominance approach helps free the analysis from difficult measurement and normative choices, and thus helps make a policy conclusion more robust and less ambiguous. We are not aware of other studies analyzing the household incidence of environmental policies using a stochastic dominance approach, especially in a general equilibrium framework.

The remainder of the paper is as follows. Section 2 presents the analytical framework used. Section 3 presents the data and describes the policy experiments. Section 4 discusses the results. Final remarks are presented in Section 5.

2 Analytical framework

2.1 The general equilibrium model

This section provides a cursory description of the general equilibrium model used in this study. It is an improved version of the static general equilibrium model used in Dissou (2005). The model builds upon recent contributions to the literature related to the general equilibrium modelling of OBA emissions trading by Dissou (2006) and Goulder, Parry, Williams III, and Burtraw (1999). It is a static multisector general equilibrium model of the Canadian economy, with endogenous labour supply. It is suitable for analyzing the aggregate as well as the sectoral impacts of alternative environmental policies that rely on market-based instruments. The model tracks combustion CO_2 emissions emanating only from the use of fossil fuels. It disaggregates the production sector into sixty-one industries in order to take into account differences in sectoral energy intensities. The model also distinguishes six types of fossil products: coal, natural gas, motor gasoline, diesel, liquid petroleum gases and "other refined petroleum and coal products". Canada is modelled as a small open economy that produces and consumes tradable goods and where all domestic economic agents operate in a competitive framework.

2.1.1 Production structure

To produce the composite output of the representative firm in each industry, a constant-return-to-scale technology combines primary factors (labour and capital), various types of energy inputs, and material inputs. The model entails a decomposition of the production structure into a sequential decision process to make the production function weakly separable with several hierarchical sub-nests.

The representation of the technology allows for various substitution possibilities among different types of fossil fuels, between fossil and non-fossil energy, between labour and the composite of capital and energy and between the index of value-added energy and intermediate inputs. A Constant Elasticity of Substitution (CES) aggregator function is used in all nests with special values (one or zero) occasionally. Labour and physical capital are mobile across industries. The representative firm considers all (output and input) prices as given. It determines the optimal levels of input use and output production by maximizing profits, considering prices and taxes as given. It pays payroll taxes and other production taxes. Using the Armington assumption, a constant elasticity of transformation (CET) function is used to transform the output into domestic sales and exports. The firm uses a revenue maximization approach to determine the optimal level of sales in the two markets.

2.1.2 Demand structure

Households

The representative household derives income from wages, dividends, government and foreign transfers. Its preferences are represented by a Stone Geary utility function (also called "Linear Expenditure System", or LES) in which are nested different hierarchical levels of CES functions. At the top level, the representative household derives utility from leisure and from the index of consumption commodities, using the LES aggregator function. At the lower level, the index of consumption commodities is a nested CES function of all commodities available in Canada, including energy goods. In parallel to firms, the household's preference structure is sequential in order to allow substitution between energy and non-energy goods, on the one hand, and substitution among different energy products, on the other.

The government

Government revenue comes from indirect taxes on domestic goods and production activities, from taxes on international transactions (imports), and from direct taxes on the remuneration of primary factors. The government also collects the proceeds of permit sales that are recycled using different methods, which are described further in the paper. Government consumption of each commodity is fixed in real terms. Its other outlays consist of transfers to households that are also fixed in real terms, and of permit-revenue-recycling expenditures. Unless otherwise mentioned, the government adjusts the latter component of its spending so as to keep constant its budget balance.

Other components of domestic absorption

Total domestic demand for each commodity is the sum of all domestic demands by households, government and firms for consumption, intermediate production and investment. A CES function is used to capture the differentiation and imperfect substitutability between imports and domestic commodities. A cost-minimization rule allows the determination of the optimal level of each component of domestic absorption.

2.1.3 Equilibrium conditions and closure rules

The general equilibrium of the model is characterized by an allocation of goods and factors such that (i) the endogenously determined prices clear all markets, (ii) all agents respect their budget constraints, and (iii) the total level of CO_2 emissions meets the specified reduction target. As Canada is considered to be a small open economy, world import and export prices are fixed. The model is closed by considering foreign savings and government savings to be exogenous and by choosing the nominal exchange rate as the numéraire. The real exchange rate adjusts to bring about the balance of payments equilibrium.

2.1.4 Carbon dioxide emissions and carbon permits

In the DET system, the requirement to hold a permit for each unit of emission imposes a penalty on the use of fossil fuels depending on their carbon content. We consider an upstream DET system in which all suppliers and importers of fossil fuels are required to buy their permits in an auctioned market. The required amount of tradable permits related to the use of a given fossil fuel varies positively with its carbon content. If the constraint on total emissions is binding, the equilibrium permit price should be strictly positive and passed on the prices paid by the users (intermediate and final) of the fossil fuels. In a general equilibrium setting, as fossil fuels are used as intermediate inputs in some industries, the increase in their prices should impact on the consumer prices of other goods and especially on those of energy intensive goods, We discuss the recycling of the permit proceeds in section 3.2 on the simulations' description.

2.2 Welfare analysis

We now turn to the assessment of the impact of GHG mitigation policies on social welfare[1]. Two important informational problems arise at this stage. The first is to estimate the impact of price changes on individual welfare. The second problem resides in the choice of a social evaluation function with which the social (or global) impact is to be assessed. We consider each problem in turn.

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[1] Note that we do not include in this analysis the environmental benefits of a reduced level of pollution.

2.2.1 The impact of price changes on individual welfare

To address the difficulty of estimating the impact of price changes on the distribution of individual welfare, we focus on the impact of *marginal* GHG reforms. To see what this means, let the direct utility function of individual i be defined by

$$U_i(x_i^1, \ldots, x_i^J; y_i) \tag{1}$$

and his budget constraint be given by

$$y_i = \sum_{j=1}^{J} q_j x_i^j + \sum_{j=J+1}^{K} q_j x_i^j, \tag{2}$$

where $q_j = r_j(1+\tau_j)$ is the market price of good j, r_j is the producer price of good j, τ_j is the tax rate on good j, y_i is the exogenous income of individual i, x_i^j is the net demand for good j from individual i (including net savings and the net demand for production factors), $j = 1, ..., J$ are consumption goods, and $j = J+1, ..., K$ are the production factors provided by households (for which the net demand x_i^j is thus negative). In a general equilibrium setting, we can think of r_j as a function of the tax rates that are applied to the different factor incomes and consumption goods, $\tau = (\tau_1, \ldots, \tau_J)$. This gives $r_j(\tau)$.

Letting $Q = (q_1, q_2, \ldots, q_J)$ be the vector of market prices, the indirect utility function for individual i is then given by $V_i(Q; y)$, with expenditure function $e_i(Q; V)$ and associated equivalent income function ν_i provided by

$$\nu_i(Q^R; Q; y_i) \equiv e_i(Q^R; V(Q; y_i)), \tag{3}$$

where Q^R acts as a vector of "reference" prices q_j^R. The equivalent function $\nu_i(Q^R; Q; y)$ gives the level of exogenous income that is needed for i to enjoy utility $V_i(Q; y)$ at prices Q^R.

To compute the individual welfare effect of a marginal change in prices, we fix reference prices to the initial ones ($Q = Q^R$) and note that the effect of such a marginal change on equivalent income is given by

$$\left.\frac{\partial \nu_i(Q^R; Q; y_i))}{\partial q_j}\right|_{Q=Q^R} = \left.\frac{\partial e_i(Q^R; V(Q; y_i))}{\partial V(Q; y_i)}\right|_{Q=Q^R} \left.\frac{\partial V(Q, y_i))}{\partial q_j}\right|_{Q=Q^R} \tag{4}$$

$$= \left[\frac{\partial V(Q^R; y_i)}{\partial y}\right]^{-1} \underbrace{\left[\frac{\partial V(Q^R; y_i)}{\partial y}\right] \left[-x_i^j\left(Q^R\right)\right]}_{\text{by Roy's identity}} \tag{5}$$

$$= -x_i^j\left(Q^R\right), \tag{6}$$

where $x_i^j\left(Q^R\right)$ is demand at prices Q^R. The total differential of the equivalent income function is then given by:

$$
\begin{aligned}
d\nu_i(Q^R;Q;y) &= \sum_{j=1}^{K} \left.\frac{\partial \nu_i(Q^R;Q;y_i))}{\partial q_j}\right|_{Q=Q^R} dq_j \\
&= -\sum_{j=1}^{K} x_i^j\left(Q^R\right) dq_j. \qquad (7)
\end{aligned}
$$

This is the total change in individual welfare[2]. As is customary, we measure initial welfare Y by the sum of exogenous income and factor incomes:

$$
Y_i = y_i - \sum_{j=J+1}^{K} q_j^R x_i^j\left(Q^R\right). \qquad (8)
$$

Let $F(y)$ be the cumulative distribution function of Y, and let $Y(p)$ denote the quantile of initial individual welfare at rank (or percentile) p.[3] Roughly speaking, $Y(p)$ is the initial welfare of the individual whose rank is p in the Y distribution. At rank p in the Y distribution, the effect on individual welfare of a marginal change in the price of good j is then

$$
B^j(p;Q^R) = -x^j(p;Q^R)dq_j, \qquad (9)
$$

where $x^j(p;Q^R)$ is the consumption of good j at rank p. The combined effect at p of the marginal changes in all prices is then

$$
B(p;Q^R) = \sum_{j=1}^{K} B^j(p;Q^R), \qquad (10)
$$

and the cumulative effect up to rank p is given by

$$
CB(p;Q^R) = \int_0^p B(q;Q^R)dq. \qquad (11)
$$

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[2] This is strictly valid only for small (infinitesimal) price changes. For price changes that are not infinitely small, the impact on an exact measure of individual welfare differs from (7) by about one half the compensated price elasticity of good j times dq_j/q_j — see Duclos, Makdissi, and Wodon (2004).) Take for instance the case of a good whose compensated price elasticity equals 1, and note from Tables 3 that the price changes modelled in this paper do not exceed 17%. Using (7) to approximate the impact of a 17% increase in the price of that good will then lead to an error of about 8.5% in the estimate of the total welfare change induced by that price change. An error of that magnitude would seem reasonably small enough for the purposes of this paper.

[3] $Y(p)$ is given by $F^{-1}(p)$, the (left) inverse of $F(y)$, namely by $F^{-1}(p) = \inf\{s > 0\,|F(s) \geq p\}$.

2.2.2 The impact of price changes on social welfare

Estimating the impact of price changes on *social* welfare poses a second fundamental problem since any particular selection of functional form and parameters for a social evaluation function (SEF) necessarily embodies arbitrary value judgements. To address this problem, we will assess the impact of price changes on *classes* of SEFs.

It is useful to define these classes by referring to "orders of normative judgements"[4]. A normative judgement of order s is characterized by a set of normative properties that SEFs must respect, and thus serves to define a class of SEFs also of order s. A first natural normative property is that a society should be judged improved whenever the welfare of one of its members increases and no one else's income decreases — we will refer to this below as the *Paretian* property. Another natural property is that SEFs should be *anonymous* in individual welfare; *viz*, permuting welfare across individuals should not affect the value of the functions. The class of first-order SEFs then regroups all of the functions that are Paretian and that obey the anonymity property.

Note that this framework is general enough to let first-order SEFs use individual welfare levels that are censored at z, where z can be interpreted as a "poverty line". Such censoring effectively limits the applicability of the Paretian property to an interval $[0, z]$ of individual welfare. A SEF is then *insensitive* to changes in welfare outside this interval. This is equivalent to using poverty indices as special cases of SEFs — see for instance Blackorby and Donaldson (1980) and Zheng (1997). Because of this, the SEFs defined above also include poverty indices.

Note also that the class of first-order SEFs is very broad. It encompasses almost the entire set of specific SEFs and poverty indices that have been proposed in the literature. This includes the Atkinson (1970) SEFs and the Gini SEFs (Sen 1973) as well as the very popular headcount, average poverty gap and FGT poverty indices (see Foster, Greer, and Thorbecke 1984).

Moving to the second-order class of SEFs is done by imposing an additional normative property, which is that the functions must register a social improvement whenever a mean-preserving redistributive transfer of individual welfare takes place from a richer to a poorer individual. This corresponds to imposing the well-known *Pigou-Dalton* principle on social judgements. The second-order class of SEFs thus contains all of the first-order functions that are more sensitive to changes in the welfare of the poorer than of the richer. Note therefore that all

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[4] This paper will use only the first two orders of dominance, but the methodology could be extended to higher-order dominance analysis.

of the first-order functions belong to the second-order class of functions. Again, these functions can censor individual welfare at z and thus also include poverty indices.

Whether a GHG mitigation policy improves *all* of the SEFs that are members of a class of order s is empirically tested through comparisons of *stochastic dominance curves*, also of order s. To see this, it is useful to consider how stochastic dominance curves are affected by changes in individual welfare brought about by GHG mitigation policies. A stochastic dominance curve of normative order s is given by (see Duclos and Araar 2006, Part III)

$$P(z;s) = \int_0^1 g(p,z)^{s-1}dp, \tag{12}$$

where $g(p,z) = \max(0, z - Y(p))$. Let $f(z) \equiv F'(z)$ be the density of individual welfare at z. Using (6), the change in these curves due to a marginal change in the price of good j is given by

$$MP^j(z;s) = \left.\frac{\partial P(z;s)}{\partial q_j}\right|_{Q=Q^R} \tag{13}$$

$$= \begin{cases} -B^j(F^{-1}(z);Q^R)f(z) & \text{if } s=1, \\ -(s-1)\left[\int_0^1 g(p;z)^{(s-2)}B^j(p;Q^R)dp\right] & \text{if } s>1. \end{cases} \tag{14}$$

The total differential of the dominance curves — namely, the total effect on the dominance curves of the changes in all prices — is then

$$MP(z;s) = \sum_{j=1}^{J} MP^j(z;s)dq_j \tag{15}$$

$$= \begin{cases} -B(F^{-1}(z);Q^R)f(z) & \text{if } s=1, \\ -(s-1)\int_0^p g(p,z)^{(s-2)}B(p;Q^R)dq & \text{if } s>1. \end{cases} \tag{16}$$

Letting z^+ be an upper bound for the intervals $[0,z]$ of individual welfare in which we may be interested, we can then state the following result:

Theorem 1 *The following conditions are equivalent:*

1. *A GHG mitigation policy improves social welfare for all social evaluation functions that are anonymous, Paretian and whose individual indicators of welfare are censored at no more than* z^+*;*

2. *A GHG mitigation policy decreases poverty for all of the poverty indices that are anonymous, Paretian and whose poverty line is no greater than z^+;*

3. *The post-GHG mitigation policy first-order dominates the pre-policy distribution up to z^+;*

4. $$B(p; Q^R) \geq 0 \, \forall p \in [0, F(z^+)]; \tag{17}$$

5. $$MP(\zeta; s = 0) \leq 0 \, \forall \zeta \ \in [0, z^+]. \tag{18}$$

Proof. See the appendix. ■

Imposing the Pigou-Dalton property on the SEFs leads to the following equivalent conditions:

Theorem 2 *The following conditions are equivalent:*

1. *A GHG mitigation policy improves social welfare for all social evaluation functions that are anonymous, Paretian, obey the Pigou-Dalton principle, and whose individual indicators of welfare are censored at no more than z^+;*

2. *A GHG mitigation policy decreases poverty for all of the poverty indices that are anonymous, Paretian, obey the Pigou-Dalton principle and whose poverty line is no greater than z^+;*

3. *The post-GHG mitigation policy second-order dominates the pre-policy distribution up to z^+;*

4. $$CB(p; Q^R) \geq 0 \, \forall p \in [0, F(z^+)]; \tag{19}$$

5. $$MP(\zeta; s = 1) \leq 0 \, \forall \zeta \ \in [0, z^+]. \tag{20}$$

Proof. The proof is analogous to that of Theorem 1. ■

2.2.3 Group and price effects

We can expect price changes to contribute differently, both qualitatively and quantitatively, to $MP(z;s)$ and thus to conditions (17), (18), (19) and (20). We will explore this below by decomposing (15) across various scenarios into a sum of $MP^j(z;s)dq_j$.

We can also wish to decompose $MP(z;s)$ by population subgroups, distinguished by socio-economic characteristics, in order to check whether a GHG mitigation policy will benefit unambiguously all such groups, and, if not, which are the winning and losing groups from such a policy, and which will weigh most in the overall gain or loss to society. This will be particularly useful in a context in which the socio-economic groups that form a society are heterogeneous in terms of consumption behavior and factor endowments, since it is in those cases that uniform price changes across a society can lead to heterogeneity in welfare impacts.

To see how to do this, let $g = 1, ..., G$ represent G exclusive and exhaustive socio-economic groups. Let the population share of group g equal π_g, and let group g's normalized density of welfare at z be given by $f_g(z)$, with $\int f_g(z)dz = 1$ and $\sum_{g=1}^{G} \pi_g = 1$. Let $x_g^j(p;Q)$ be the average consumption of good j among those in group g who are also at rank p in the population distribution of welfare. We can then denote $B_g^j(p;Q^R) = -x_g^j(p;Q^R)dq_j$ as the loss of group g's welfare at rank p that comes from an increase in the price of good j, $B_g(p;Q^R) = \sum_{j=1}^{K} B_g^j(p;Q^R)$ as the combined welfare loss on group g at p that results from all price changes, and $CB_g(p;Q^R) = \int_0^{F^{-1}(p)} B_g(F(z);Q^R)f_g(z)dz$ as the price changes' cumulative effect on group g up to rank p. For first-order and second-order dominance, we then define

$$MP_g(z;s) = \begin{cases} -B_g(F^{-1}(z);Q^R) & \text{if } s = 1, \\ -CB_g(F(z);Q^R) & \text{if } s = 2, \end{cases} \tag{21}$$

and can then re-express $MP(z;s)$ in (15) as

$$MP(z;s) = \sum_{g=1}^{G} \pi_g f_g(z) MP_g(z;s). \tag{22}$$

The population $MP(z;s)$ is thus a mean (weighted by population shares) of the changes in welfare across groups. It can therefore happen that the conditions of

Theorems 1 and 2 may hold at the population level, but not at some subgroup level. We will explore this further in Section 4.

3 Data and simulation description

3.1 Data

Two types of data sets are used in this study. The first pertains to the calibration of the computable general equilibrium (CGE) model, and the second, which consists of household-level data, is used for the dominance analysis. The calibration of the CGE model is based on the social accounting matrix (SAM) and on industrial and household CO_2 emissions data for the 2004 Canadian economy. The latter is the latest year for which we were able to obtain the full Canadian household survey dataset.

A SAM consistently presents transaction flows among economic agents and production factors by combining data from input-output tables and national income accounts, trade statistics and government accounts. The SAM's input-output section is extremely useful for the breakdown of CO_2 emissions by industry and by fuel type. The SAM used in this study was built using the input-output table of 2002 produced by Statistics Canada. This SAM is consistent with the latest available detailed CO_2 emissions by industry and by fuel of the same year, also produced by Statistics Canada. Using the RAS method[5], we updated the input-output table and the 2002 emissions data to obtain input-output data that are consistent with national account data and total 2004 CO_2 emissions.

Among other characteristics, the SAM distinguishes 61 industries, 65 commodities, one representative household, two primary factors, *i.e.*, labour and capital, and one consolidated government sector. The extraneous behavioral parameters used in the calibration process consist essentially of the values of substitution elasticities in the CES and CET functions used for representing household preferences, firm technology and trade relationships. Due to space constraints, we only present in Table 1 the ranges of the values of these external parameters that are similar to the ones used in other studies on the Canadian economy (Ab Iorwerth et al, 2000; and Wigle, 2001).

The dominance analysis is performed using the 2004 Canadian Survey of Household Spending (SHS) carried out by Statistics Canada. This survey provides detailed information on household income and expenditures including gasoline

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[5] See Bacharach (1970)

and other energy goods. It is a nationwide survey that covers 98% of the population of private households in Canada's 10 provinces. Households are asked to provide information that includes among other items, their expenditures on goods and services, their dwelling characteristics and their annual income for the year 2004.

The original sample covered 20,446 households. Because of non-responses, refusals, and other factors, only 14,154 households are used in this paper. The survey uses a stratified double-stage sampling approach in which clusters are selected in the first stage from the Canadian Labor Force Survey sampling frame, and households are then selected in the second stage within the selected clusters. In order to be representative of the population, the survey also provides weights computed from the sampling frame of the 2001 census of the Canadian population. In addition to using household size and household sampling weights to weight households, all monetary variables are expressed in *per capita* terms. This is because it is individual welfare that matters, although consumption is observed at the household level.

Data on household spending cover outlays on 21 commodities; income variables include labor income, investment income and other income. As is usual in many countries, consumption expenditures from surveys of household spending do not match exactly those found in the system of national accounts, in part because of methodological and classification differences. As a result, the mapping between the two classifications of goods and services is not straightforward. The commodity disaggregation used in the CGE model, which is an aggregation of commodities in Statistics Canada's input-output table (at the "L-level" of 113 industries), is richer than the one in the survey of household spending (65 commodities in the former *vs.* 21 in the latter). We mapped each commodity in the SHS to the closest possible match in the model disaggregation. This mapping is later used for aggregating the price impacts from one sectoral disaggregation to the other.

3.2 Description of policy experiments

We run three CGE simulations with different policy settings to assess the impacts on commodity prices and primary factor incomes of reducing combustion CO_2 emissions, *i.e.*, those associated with the use of fossil fuels in Canada. We opt to reduce these emissions by 15% in comparison to the benchmark situation. As mentioned above, the choice of this magnitude of abatement is for illustrative purposes alone and does not have a precise link with an official GHG policy in

Canada.

In all simulations, a cap-and-trade domestic emissions trading (DET) system is used to lower CO_2 emission to the desired level. In the DET, the requirement to hold permits for all residual units of emissions would increase the user price of fossil fuels. We consider the implementation of an upstream permit system in which all users of fossil fuels (for final demand and for intermediate inputs) would pay for the cost of the permits. Since a ceiling is put on total emissions and international permits are not available, the permit price is endogenously determined by the model so as to achieve the specified target. The three simulations differ by the recycling method of the permit proceeds.

In the first simulation (named OBA), the permit revenue is used to provide rebates to firms for the permit cost they incur. The value of the rebate is the product of current output, of the adjusted benchmark emission intensity, and of the permit price. In the OBA DET firms are initially assigned a benchmark emission intensity that will be used to compute the rebate. These benchmark emission intensities are endogenously adjusted by a common scaleback factor in order to equalize government revenue-recycling expenditures and actual subsidies received by firms. As discussed in Dissou (2006) and Bernard, Fischer, and Fox (2007), this form of rebate, which is gaining popularity among policy makers and researchers, provides an output subsidy. Although OBA does provide firms an incentive to reduce their actual emissions intensity, it does not provide them an incentive also to reduce their output in order to cut total emissions. As a consequence, firms will reduce less their use of labor and capital in the OBA system. Note that the firm's actual emissions intensity after abatement is not necessarily identical to the benchmark value that is used to determine the rebate. Depending on the permit price, actual emissions intensity might increase in comparison to its benchmark value in some industries, while it might decrease in other industries. The difference in actual emissions intensities achieved by firms is the main driver of emissions trading in this closed system. Over-performing firms that reduce their emissions so as to reduce their emissions intensity below the assigned level will sell emissions credits to under-performing firms.

In the second simulation, named RPT, the permit proceeds are used to reduce the payroll taxes paid by firms to the government. Finally, in the third simulation named UCS, permit proceeds are used to reduce existing consumption taxes on all goods by a uniform percentage. This could be seen as a uniform subsidy on consumption goods.

4 Results and discussions

4.1 CGE results

We first present a cursory review of the general equilibrium results of the three simulations in order to help grasp the source of the consumption and factor price changes that are used in the distributive analysis. Table 3 presents the price impacts of the GHG mitigation policy in the three simulations using the disaggregation present in the SHS data. As alluded to previously, the price impacts in that table are obtained by aggregating the consumption price impacts generated by the model using a mapping between the models sectoral disaggregation and that of the SHS.

As is usual in a CGE, the final impacts on prices cannot be isolated from changes in quantities and changes in aggregate variables. Table 2 reports the impacts on some aggregate variables and the Annex Table 4 shows the impact on sectoral real variables using the original model disaggregation. Even though the results in the latter table are not directly used in the dominance analysis, they help in understanding the magnitudes and the signs of the price changes. Due to space constraints, we only present the sectoral results for real variables related to the first OBA simulation with an output-based allocation of permits.

As shown in Table 3, in the three simulations, energy prices increase in conformity with the main objective of market-based instruments that aim at reducing the use of fossil fuels through an increase in prices. The latter increase is brought about by the cost of emissions abatement and the requirement to buy permits for residual emissions. The prices of the tradable permits are \$16.0, \$12.6, and \$12.4 per ton of CO_2 in, respectively, OBA, RPT and UCS. The higher cost of permits in OBA is by no means a surprise. Indeed, as it has been pointed out by previous studies (Dissou 2006, and Bernard, Fischer, and Fox 2007) that a main drawback of a DET with output-based allocation of permits is the large increase in the marginal cost of abatement that is a consequence of the indirect output subsidy provided to firms.

The prices of fossil energy products increase within a range of 9.6% for natural gas under UCS to 16.6% for gasoline under OBA. The ranking of the price changes of energy fossil products in the three scenarios follows that of the permit price. The increases in the prices of fossil energy products under OBA are higher than those in RPT, which are larger than those in UCS. The small magnitude of the change in the price of electricity is due to the significant share of hydroelectricity (around 40%) in total electricity generation in Canada. In the OBA simulation, the price of electricity even decreases slightly as a result of the output subsidy. As expected, Table 4 shows a fall in the demand for energy products; a change in the demand composition toward non-energy goods is also observed. In general, and in comparison with the benchmark situation, the supply of non-energy goods increases (or falls less) than that of energy goods.

The increases in energy prices affect negatively energy-intensive industries through a cost-push shock that puts an upward pressure on the prices of their products. Still, in a general equilibrium context, this negative supply shock should not necessarily translate into an increase in the prices of energy-intensive goods because of the potential negative effects on demand also initiated by the energy price increase. For, as shown in Table 3, as energy prices rise, returns to labor and capital could fall, and household real income could thereby drop. This is particular true in the UCS where these factors do not benefit from any positive measure from revenue recycling. Labour and capital remunerations fall by respectively 0.69 % and 1.46% under UCS. In the RPT scenario, the rental rate of capital decreases by 1.69% while the wage rate increase thanks to the reduction in payroll taxes. Under OBA, both factors benefit from the output subsidy and their remunerations increase slightly.

The changes in factor incomes affect household demand for goods and in some scenarios dampen the initial upward pressure on the prices of energy-intensive goods. When the downward pressure on these prices dominates the ascending movement, the prices of most goods decline. Referring to Table 3, the prices of non-energy goods fall by a higher magnitude in the UCS scenario where both labour and capital incomes fall, in comparison with the two the simulations where the returns to one or to both factors increase. Partial equilibrium analyses that consider the change in energy prices alone cannot account for the impact on other prices. This result provides a strong case for using a general equilibrium framework when the change in energy prices has strong spill-over effects. Overall, aggregate household real consumption increases the most under RPT (0.35%) and decreases by 0.27% under OBA.

The simulation results confirm the view of Fullerton and Heutel (2007) on the impact of GHG abatement policies on the relative return of capital *vs* labour. They argue that, as polluting industries are capital intensive in comparison to non-polluting ones, abatement policies are more likely to depress the return to capital more than the return to labor. The rental rate of capital is more affected than the wage rate; the former decrease more (or increases less) than the latter. As affluent consumers derive a higher share of their income from capital than less affluent ones, this effect could have important implications regarding the distributive impact of GHG abatement policies.

4.2 Distributional analysis

We now turn to the distributive and social welfare impact of the GHG abatement policies considered in this paper. Table 5 describes summarily the distribution of population shares and total expenditures. *Per capita* total expenditures in Canada were about \$CAN 17,600 in 2004. The majority of the population had total *per capita* expenditures situated in the interval of \$CAN $[10,000; 20,000]$. Figure 1 shows the estimates of the marginal impact $MP(z;s)$, defined by (15), of the three potential GHG mitigation policies on the first-order dominance curve, as well as 95% confidence intervals around the estimates. All three policies have a negative (positive) impact on welfare (poverty), which is expected since a fall in well-being can be rationalized as the cost that society must pay to improve its environment. UCS ("Universal Consumer Subsidy") appears least costly; OBA ("Output-Based Allocation of Permits"), the most. This is also the case for second-order dominance, as shown in Figure 2.

4.2.1 Testing

Following Theorems 1 and 2, one can state formally that a GHG mitigation policy A leads to a greater increase in social welfare for individual welfare censored at z^+ (or a smaller increase in poverty for poverty lines below z^+) than a policy B at order s if and only if:

$$\Delta^s(z) = MP_A(z;s) - MP_B(z;s) < 0 \; \forall \, z \in [0, z^+]. \tag{23}$$

For statistical tests of dominance of one policy over another, a natural formulation of a null hypothesis is thus that of a union of null hypotheses

$$H_0 : \Delta^s(z) < 0 \text{ for some } z \in [0, z^+] \tag{24}$$

to be tested against an alternative hypothesis that is an intersection of alternative hypotheses

$$H_1 : \Delta^s(z) \geq 0 \text{ for all } z \in [0, z^+]. \tag{25}$$

The decision rule we adopt is then to reject the union set of null hypotheses (non-dominance) in favor of the intersection set of alternative hypotheses (dominance) only if we can reject each of the individual hypotheses in the null set at a $100 \cdot \theta\%$

significance level. Graphically, this can be conveniently carried out using a $100 \cdot (1-\theta)\%$ one-sided confidence interval.

To see this in greater details, denote by $\hat{\Delta}^s(z)$ the sample estimator of $\Delta^s(z)$, by $\Delta_0^s(z)$ its sample value, and by $\sigma^2_{\hat{\Delta}^s(z)}$ the sampling variance of $\hat{\Delta}^s(z)$. Let $\zeta(\theta)$ be the $(1-\theta)$-quantile of the normal distribution. Given that by the law of large numbers and the central limit theorem, all of the estimators used in this paper can be shown to be consistent and asymptotically normally distributed, we can use $\Delta_0^s(z) \pm \sigma_{\hat{\Delta}^s(z)}\zeta(\theta)$ as alternative lower and upper bounds for one-sided confidence intervals for $\Delta^s(z)$. For instance, an upper-bounded confidence interval $\Delta_0^s(z) + \sigma_{\hat{\Delta}^s(z)}\zeta(\theta)$ shows all of the values of a constant η for which we could not reject the null hypothesis $H_0 : \Delta^s(z) > \eta$ in favor of $H_1 : \Delta^s(z) \leq \eta$. Our decision rule is then to reject the set of null hypotheses (24) in favor of (25) if and only if:

$$\Delta_0^s(z) + \sigma_{\hat{\Delta}^s(z)}\zeta(\theta) < 0 \, \forall z \in [0, z^+]. \tag{26}$$

The confidence intervals that appear in Figures 1 and 2 are not sufficient to infer differences in the $MP(z;s)$ curves since the covariance between the estimates of these curves is not null. A more useful figure shows estimates of the differences between the $MP(z;s)$ curves as well as the confidence intervals around these differences, taking into account the correlation between the point estimates of the curves. This is shown in Figure 3, where UCS statistically first-order dominates RPT in poverty and welfare for any choice of z^+ below $CAN18,600. Second order dominance of UCS is obtained in Figure 4 for any choice of z^+. Figures 5 and 6 analogously confirm the dominance of RPT over OBA. These dominance results are summarized in Table 8.

4.2.2 Effect of price changes

To investigate the sources of the changes in welfare that the three policies would generate, we decompose the total impact on welfare of the price changes into a sum of $B^j(p; Q^R)$ (see (9) and (10)) coming from four different sets of price effects:

- those that arise from changes in factor prices (labor and capital);
- those that arise from changes in food prices;
- those that arise from changes in energy prices (electricity, natural gas, gasoline and other fuels for owned and leased vehicles);

- and those that arise from changes in the prices of other goods and services.

Figure 7 uses non-parametric smoothing (kernel) estimation techniques to show the impact $B^j(F^{-1}(z); Q^R)$ of each of these sets of price changes at different poverty lines (z) in the context of the UCS policy. A negative impact on welfare is contributed by income and energy components and a positive one from the change in the prices of other goods. This result is not surprising since is explained by the nature of the general equilibrium price changes shown in Table 3. Note, however, that in Figures 8 and 9, the income change component increases wellbeing in the context of OBA and RPT; this in fact distinguishes in large part the OBA and RPT policies from the UCS one. For all policies, the energy effect decreases welfare.

4.2.3 Regional tests

We can also check whether heterogeneity in consumption and factor endowments across socio-economic groups means that the all-Canada results shown until here do not apply uniformly across Canadian regions. We consider (21) across four regions (percentage of the total population): Ontario (39%); Quebec (23%); British Columbia (13%); and other provinces (24%).

Figure 10 shows the impact of the UCS policy across these different regions. Observe that British Columbia seems to suffer least from UCS. Figure 11 shows the upper bound of the difference between the $MP(z; s)$ curves of the other regions relative to British Columbia. The impact of UCS in British Columbia is significantly lower than in the group of other provinces; it is also significantly lower than in Ontario and in Quebec for intervals CAD\$ $[8200, \infty[$ and CAD\$ $[10000, 18300]$ respectively. Overall, however, the differences across regions are not very marked. This is in part explained by the fact that *per capita* expenditures on energy at different levels of total expenditures do not differ much across regions, as shown in Figure 12.

4.2.4 Inequality impact

In addition to the welfare and poverty impact of GHG abatement policies, one may also wish to know their impact on inequality and redistribution. Figure 13 graphs the expected proportional change in individual welfare induced by the policies at different levels of *per capita* total expenditures. Except for the bottom part of the distribution, the proportional change is roughly constant across levels of *per capita* total expenditures, which suggests that relative inequality indices (such as the Gini index) would not be much affected by the policies.

To probe this further, Table 7 presents estimates of the Gini index for the pre and post policy distributions. Overall, the policy effects on inequality is numerically small. OBA and RPT policies have a slightly more pronounced impact on inequality than UCS: they increase it significantly, as shown by the confidence intervals of the impact estimates in Table 7. This is confirmed by the differences between the post-policy Lorenz curves and the initial Lorenz curve that are shown in Figure 14. Panel A shows the estimates of the differences in the curves; Panels B, C and D plot these estimates in addition to the upper bounds of the confidence intervals around them. This confirms that OBA and RPT would lead to a statistically significant increase in inequality.

Why this is so can be seen by assessing the impact of marginal price changes on the Gini (G). This is given by[6]:

$$dG = \sum_{j=1}^{J} \frac{\mu_j}{\mu}(G - C_j)dq_j + \sum_{j=J+1}^{K} \frac{\mu_j}{\mu}(C_j - G)dq_j. \tag{27}$$

where μ_j is the population mean of good j and C_j is the concentration coefficient of good j. The linearity of (27) also makes it possible to think in terms of the combined impact of groups of goods. The results are presented in Table (8). The changes in energy prices increase inequality for all scenarios. For the UCS scenario, however, changes in food prices and in incomes completely offset that increase in inequality. This evidence therefore provides an additional argument in support of UCS as a preferable GHG policy, since UCS would not only lead to greater welfare and lower poverty, but it would also lead to lower inequality through its differential impact on prices.

5 Conclusions

This study analyzes the incidence on households of pollution control policies using an integrated framework combining a multi-sector general equilibrium model with a stochastic dominance analysis that uses household-level data. A Canadian domestic cap-and-trade emission trading (DET) system is considered in three different settings: an output-based allocation of permits (OBA), the use of

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[6] See Araar (2002) and Duclos and Araar (2006), Chapter 12.

the permit proceeds to reduce payroll taxes (RPT), and the use of the same proceeds to reduce consumption taxes by providing a uniform consumption subsidy to all commodities (UCS).

According to the results of the general equilibrium model, and as expected, DET raises the prices of fossil energy prices so as to reduce the level of emissions in the economy. The largest increase in these prices is observed with OBA, and the smallest one with UCS. The main reason for this stems from the fact that OBA provides fewer incentives to firms to reduce their output and, thereby, the permit price required to reduce emissions is the highest with that scenario. In addition to the change in energy prices, the general equilibrium model indicates that the price of most non-energy goods decrease and that both the wage rate and the rental rate of capital are affected too. Importantly, our results suggest that the return to capital is more negatively affected than the wage rate, among other reasons because polluting industries are relatively capital intensive.

The changes in commodity prices along with the changes in factor remunerations are then applied to household-level data to perform a stochastic dominance analysis of the incidence of alternative GHG mitigation policies. A key advantage of this approach is that it avoids having to choose an arbitrary social evaluation function — the choice of which could possibly affect the conclusions over the impact of policies on social welfare. Our results are thus made robust to the selection of any social evaluation function within a wide class. Statistical tests indicate that all three GHG policies impact negatively on welfare. They also suggest that RPT first-order welfare dominates OBA, that UCS first-order poverty dominates RPT for any choice of poverty thresholds below $CAN 18,600, and UCS second-order welfare (and, for all possible poverty lines, second-order poverty) dominates RPT.

Decomposing the sources of welfare changes, we also find that changes in energy prices and in factor incomes tend to depress welfare, while changes in non-energy commodity prices tend to increase it. Finally, OBA and RPT would lead to a statistically significant increase in inequality (an impact which is not statistically significant for UCS), thus providing an additional normative argument in support of UCS as a preferable GHG policy.

6 Appendices

6.1 Theorem 1

Proof. Note first that the dominance curves in (12) can be used to order dis-

tributions over classes of all of the SEFs that are anonymous, Paretian and whose individual indicators of welfare are censored at no more than z^+ — see for instance Duclos and Araar (2006), Part III). These SEFS also include all of the poverty indices that are anonymous, Paretian and whose poverty line is no greater than z^+. If and only if distribution B's dominance curve in (12) is lower than that of A over all $z \in [0, z^+]$, then B exhibits a greater level of social welfare than A over all of the above first-order SEFs. A further result is that if and only if distribution B's dominance curve in (12) is lower than that of A over all $z \in [0, z^+]$, then B has a lower level of poverty than A over all the first-order class of poverty indices with $z \in [0, z^+]$. This is also known as first-order dominance of B by A over $[0, z^+]$. The effect of a GHG mitigation policy on (12) is given by (14). (12) will therefore be pushed down over all $[0, z^+]$ by a GHG mitigation policy if and only if (14) is negative over all $[0, z^+]$, namely, if and only if (17) and (18) hold.
■

Figure 1: Change in first-order dominance curves following GHG mitigation policies

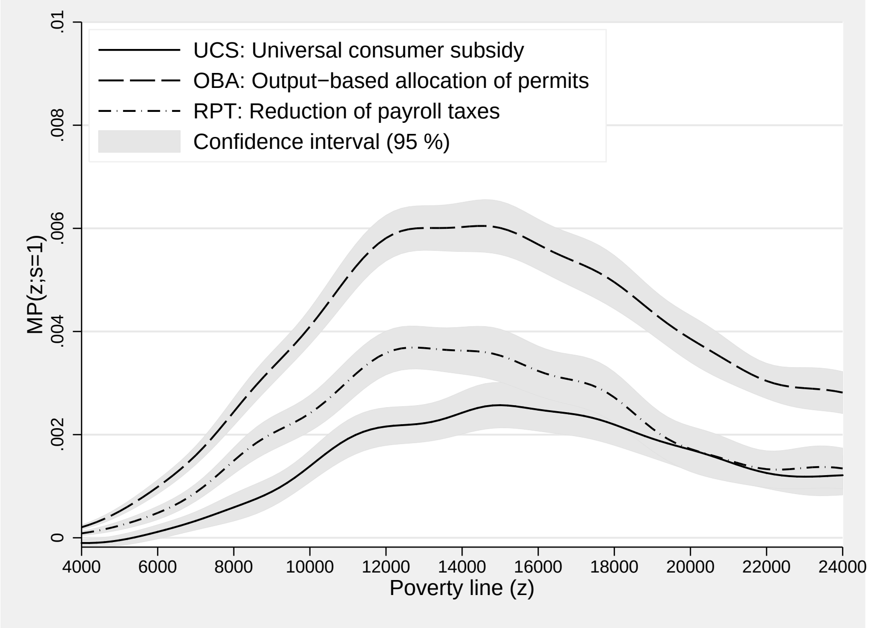


Figure 2: Change in second-order dominance curves following GHG mitigation policies

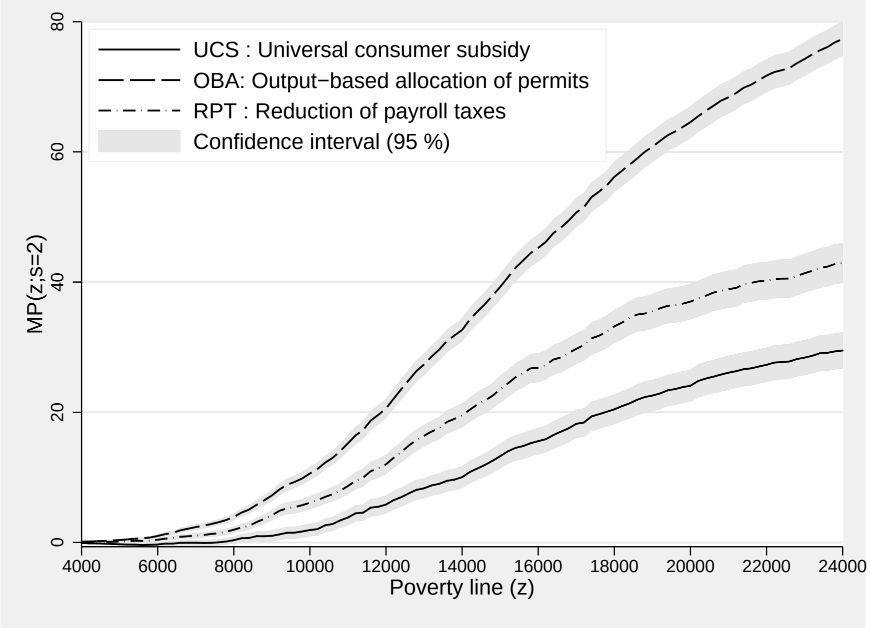


Figure 3: Difference between the first-order impact $MP(z; s = 1)$ of UCS and RPT mitigation policies

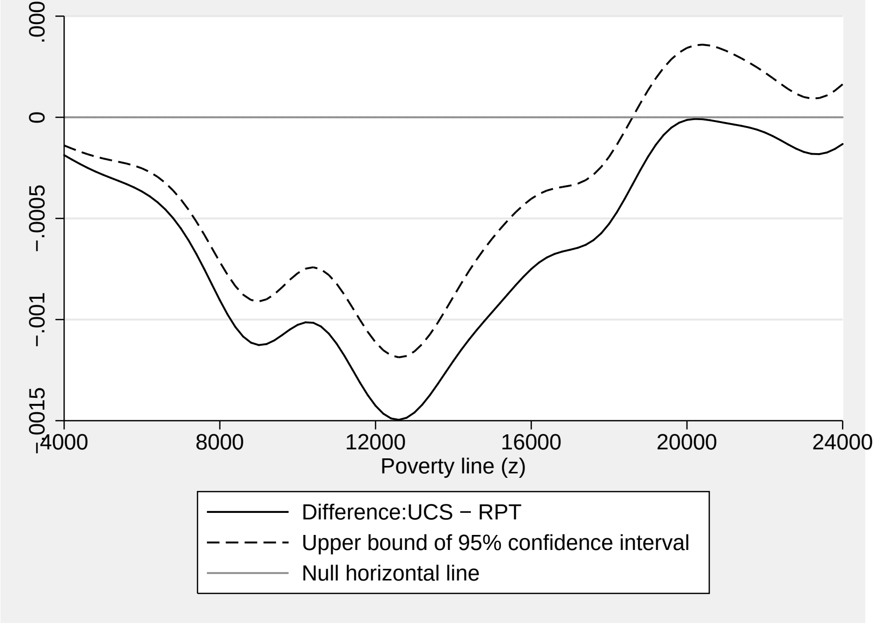


Figure 4: Difference between the second-order impact $MP(z; s = 2)$ of UCS and RPT mitigation policies

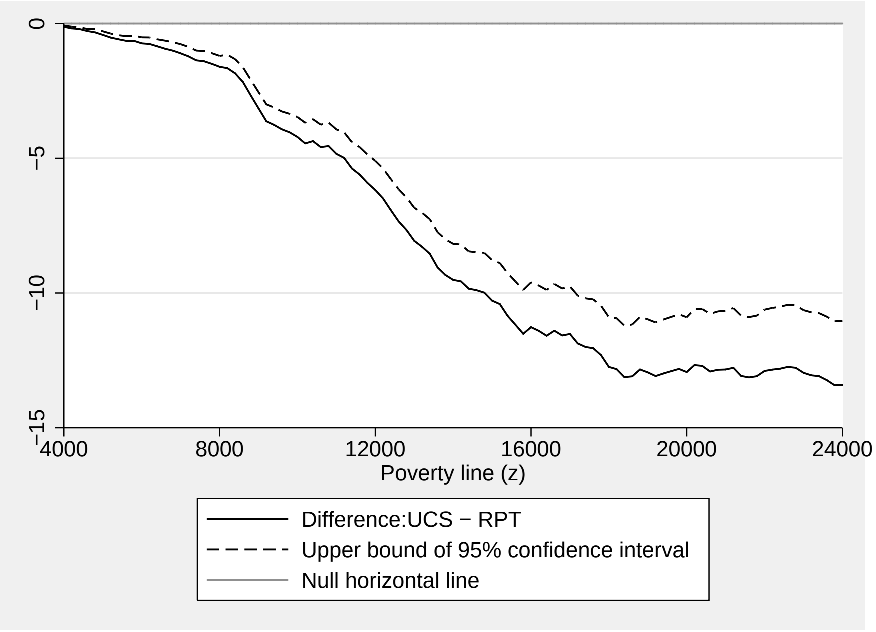


Figure 5: Difference between the first-order impact $MP(z; s = 1)$ of RPT and OBA mitigation policies

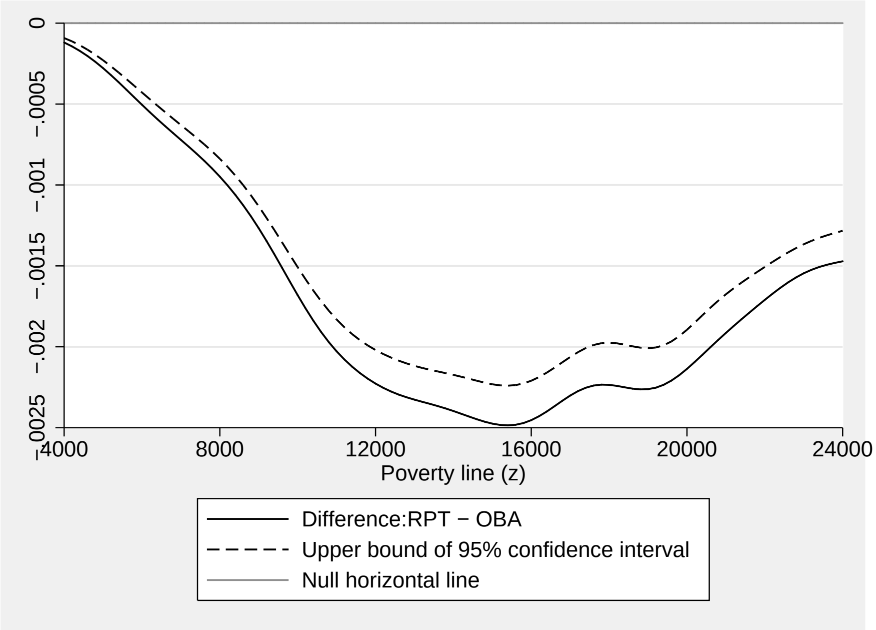


Figure 6: Difference between the second-order impact $MP(z; s = 2)$ of RPT and OBA mitigation policies

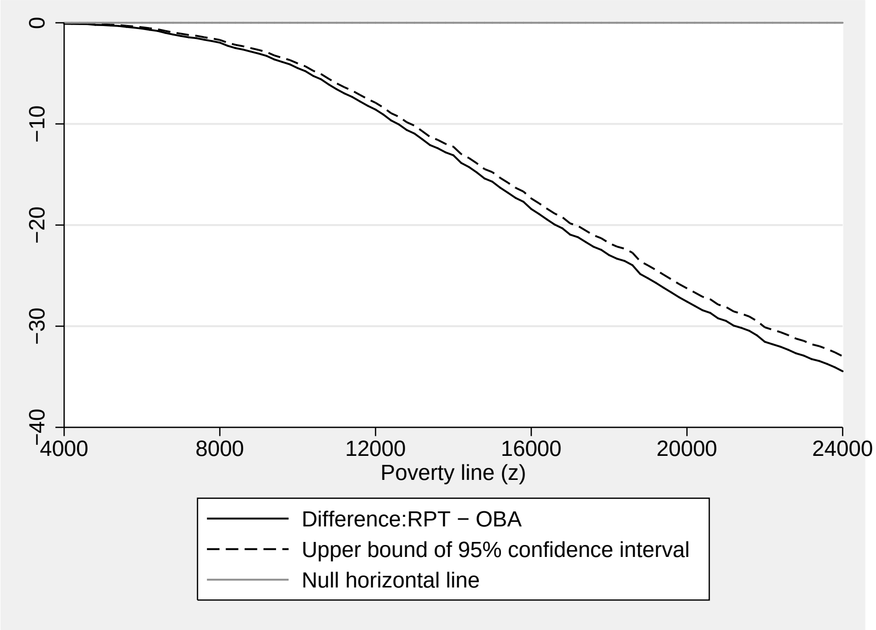


Figure 7: Impact $B^j(F^{-1}(z); Q^R)$ of different sources j of welfare changes at different levels of *per capita* expenditures (z) following a UCS policy

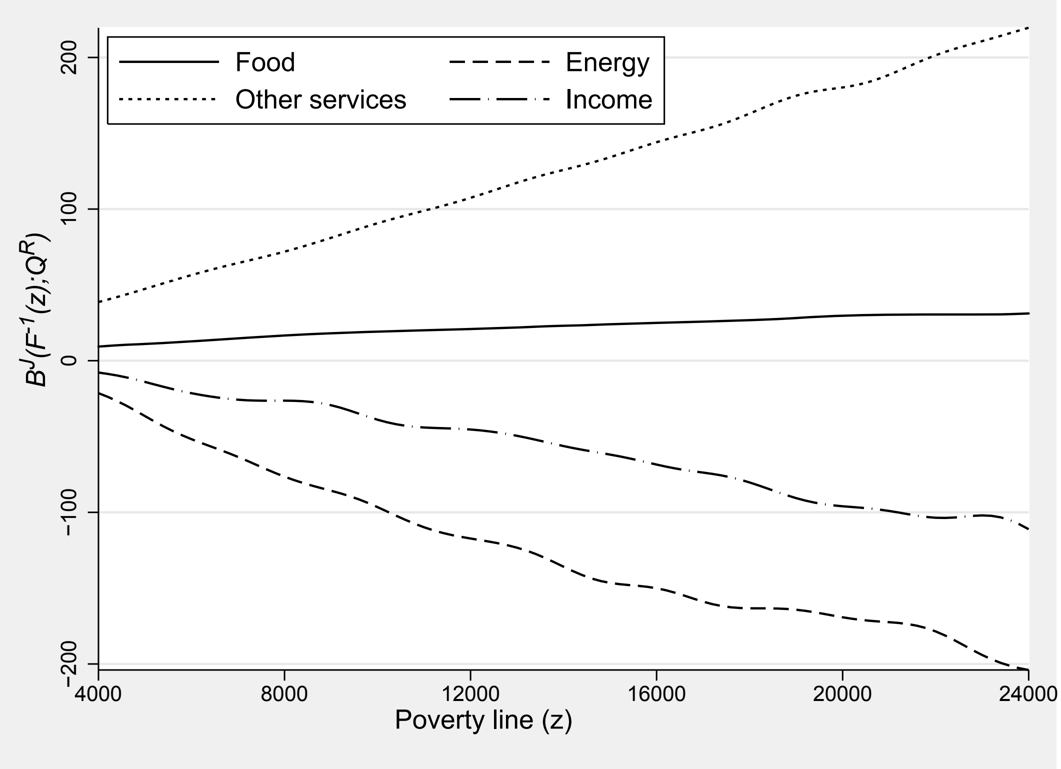


Figure 8: Impact $B^j(F^{-1}(z);Q^R)$ of different sources j of welfare changes at different levels of *per capita* expenditures (z) following an OBA policy

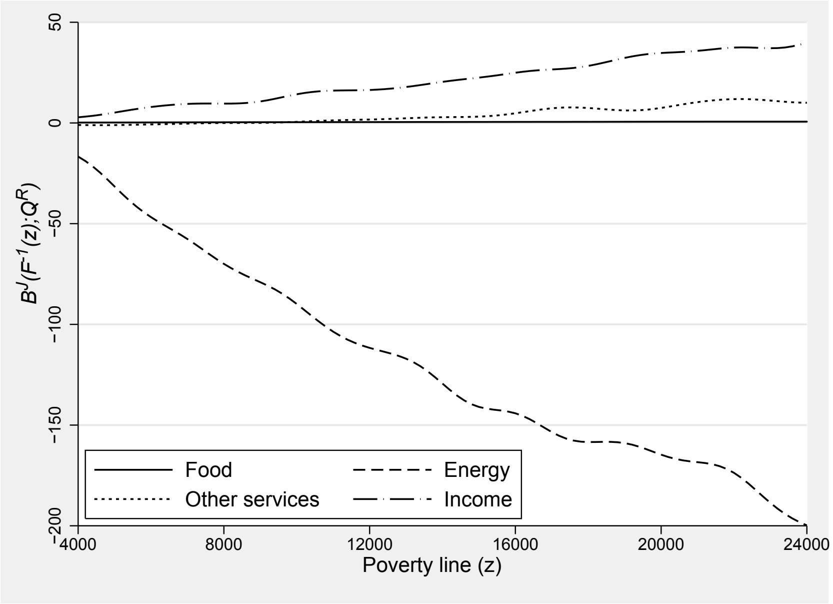


Figure 9: Impact $B^j(F^{-1}(z);Q^R)$ of different sources j of welfare changes at different levels of *per capita* expenditures (z) following a RPT policy

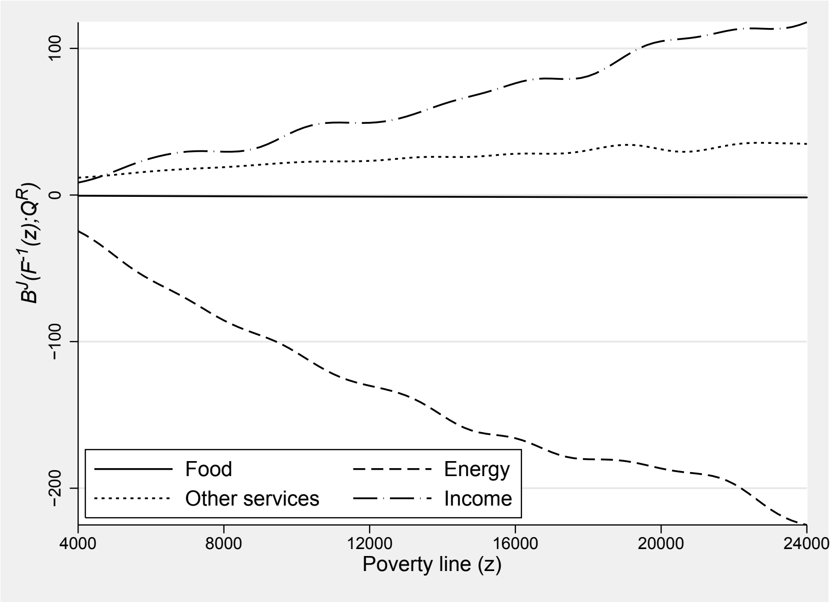


Figure 10: Impact of UCS policy across different Canadian regions, at different levels of *per capita* expenditures (z)

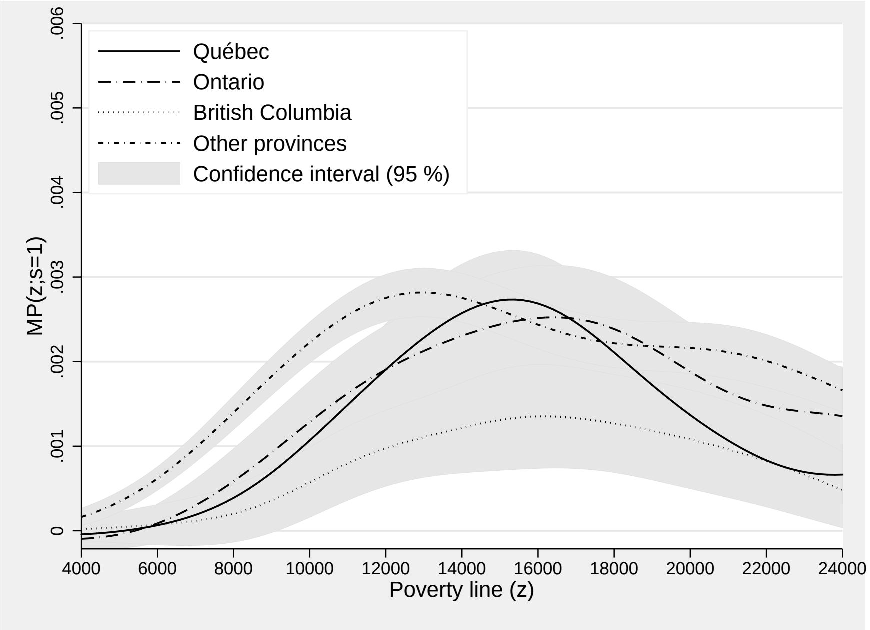


Figure 11: Upper bound of the confidence interval of the difference in the impact of a UCS policy across Canadian regions, at different levels of *per capita* expenditures (z)

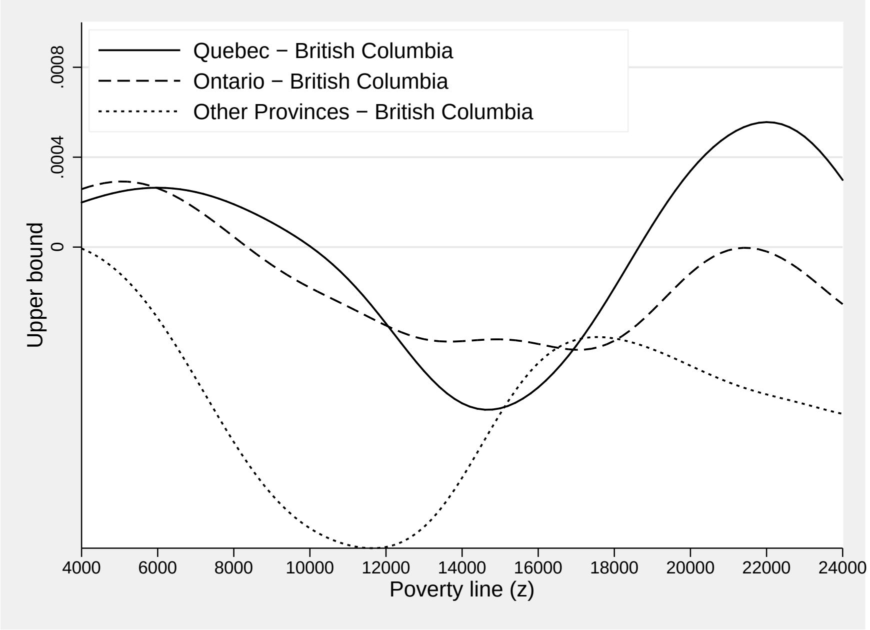


Figure 12: *Per capita* expenditures on energy across regions

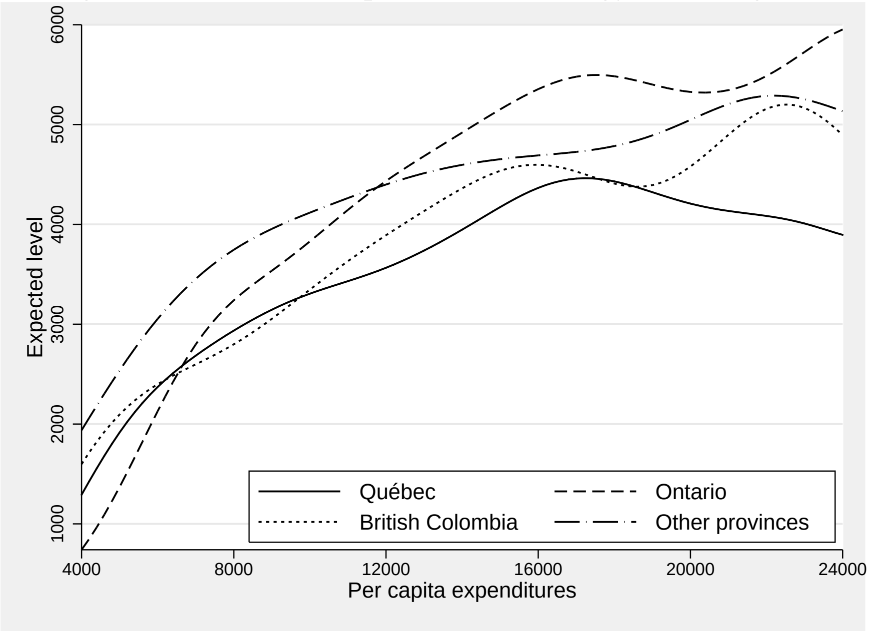


Figure 13: Proportional change in individual welfare at different levels z of *per capita* expenditures, following three possible GHG mitigation policies

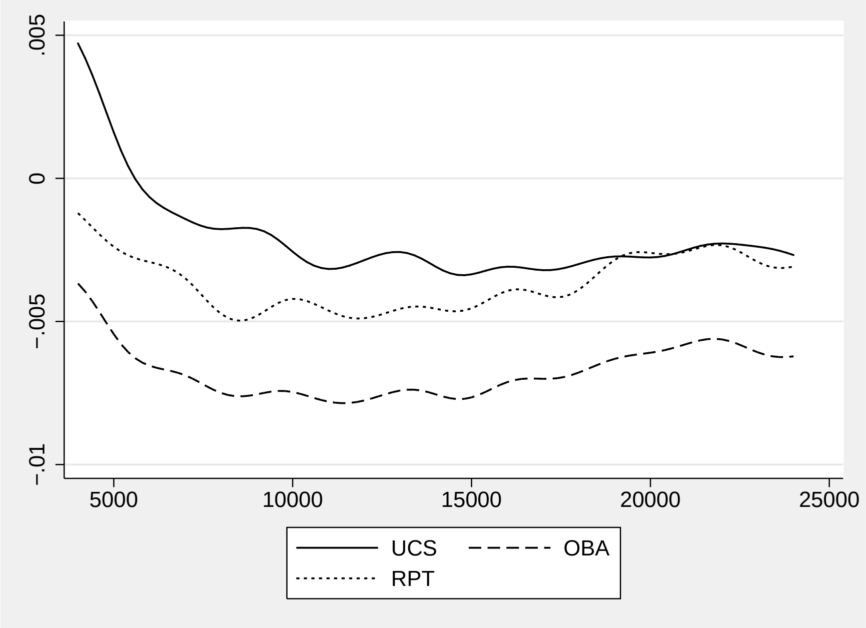
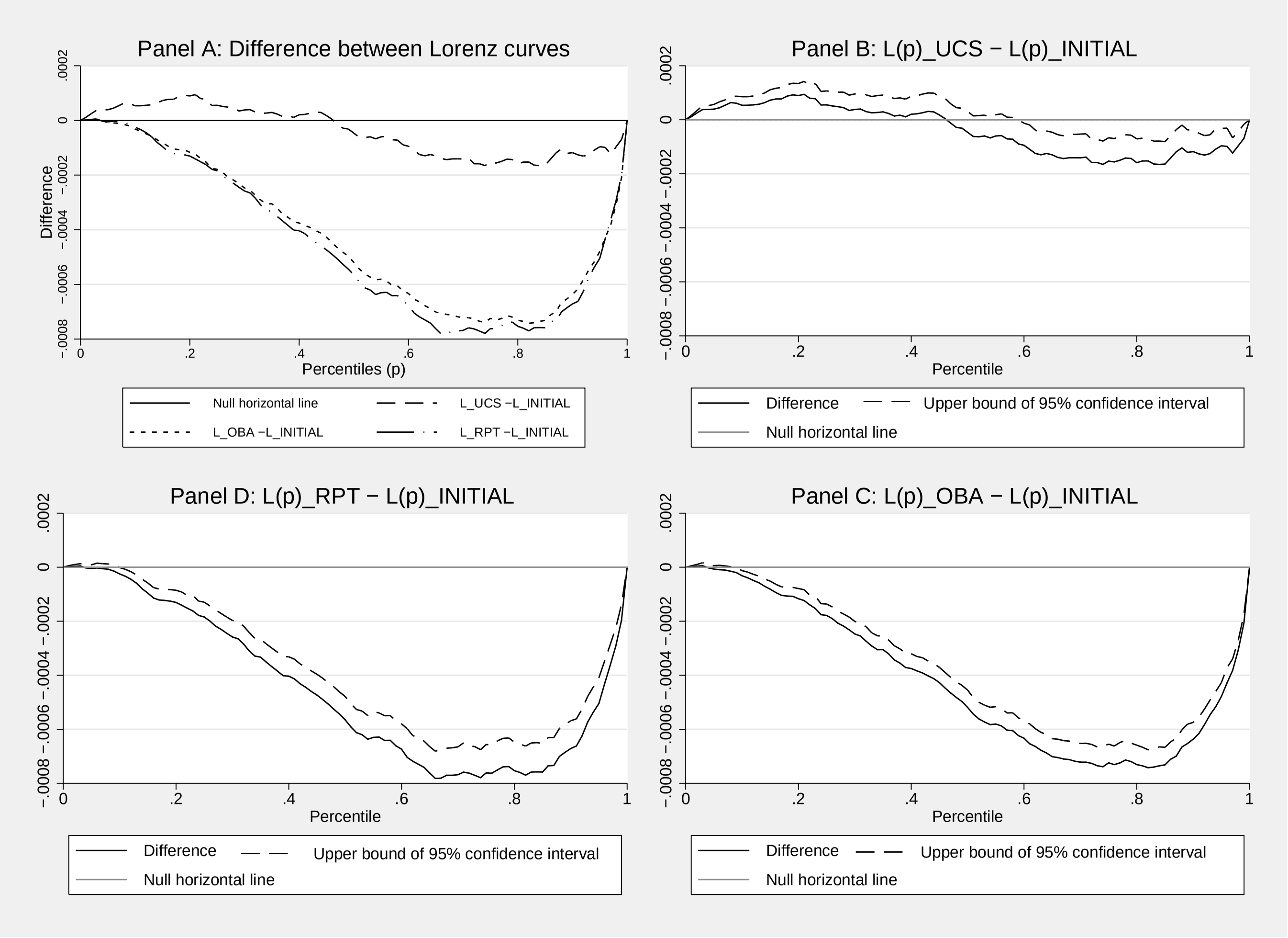


Figure 14: Differences between the post-policy Lorenz curves and the initial Lorenz curve



Panel A: Difference between Lorenz curves

Panel B: L(p)_UCS − L(p)_INITIAL

Panel D: L(p)_RPT − L(p)_INITIAL

Panel C: L(p)_OBA − L(p)_INITIAL

Table 1: Elasticities of substitution in technology used in the model

	Values or range
Between value added and index of intermediate inputs	0.2-1
Between capital and index of stationary energy inputs	0.21-1.5
Between electricity and non-motive fossil energy inputs	0.49-1.55
Between refined petroleum products and other non-motive fossil fuels	0.1-4
Among refined petroleum products	1
Between non-energy intermediate inputs and motive fuels	0.1-0.83
Among motive fuels	1
Between capital-energy and labour	1
Among non-energy intermediate inputs	0

Source: simulation results

Table 2: Aggregate impacts of 15 percent reductions in CO_2 emissions in different simulations (percentage change from base case)

	Output-based allocation of permits	Reduction in payroll taxes	Uniform consumption subsidy
Real GDP at market prices	-0.15	0.06	-0.15
Labour supply	0.03	0.35	0.02
Consumption price index	0.51	0.33	0.33
Rental rate of capital	0.22	-1.29	-1.46
Nominal wage rate	0.26	0.85	-0.69
Household real consumption	-0.27	0.35	0.08
Equivalent variation in % of non-labour income			
Government total revenue	2.83	2.35	1.35
Price of carbon permit	16.04	12.59	12.41
Percentage reduction in industrial emissions	-16.23	-17.02	-16.96
Percentage reduction in household emissions	-11.00	-8.32	-8.53
Percentage reduction in total emissions	-15.00	-15.00	-15.00

Source: simulation results

Table 3: Impacts on consumption prices of 15 percent reduction in CO_2 emissions in different simulations (percentage change from base case)

	Output-based allocation of permits	Reduction in payroll taxes	Uniform consumption subsidy
Energy			
Electricity	-3.64	1.95	0.84
Natural gas	11.00	11.07	9.64
Other fuel	12.89	12.10	11.26
Gasoline & other fuels for vehicles	16.57	16.37	15.39
Non-energy commodities			
Food	-0.02	0.05	-0.95
Shelter without water fuel & electricity	0.18	-0.94	-2.06
Water & sewage	0.42	0.45	-0.63
Household operation	0.21	-0.52	-1.47
Household furnishings & equipment	0.15	-0.26	-1.17
Clothing	0.08	-0.20	-1.06
Transportation without gasoline	-0.18	1.41	0.39
Health care	0.20	-0.55	-1.53
Personal care	0.26	-0.28	-1.26
Recreation	-0.85	-0.33	-1.03
Entertainment	-0.85	-0.33	-1.03
Recreation facilities	-0.85	-0.33	-1.03
Package trips	-0.85	-0.33	-1.03
Reading materials	-0.61	-0.07	-1.02
Education	0.17	-0.50	-1.45
Tobacco & alcohol	0.10	-0.56	-0.98
Miscellaneous expenditures	0.08	-0.19	-1.04

Source: simulation results

Table 4: Sectoral impacts of 15 percent reduction in CO_2 emissions with OBA

Commodities	Total supply	Domestic supply	Exports supply	Imports demand	Total domestic demand	Household demand	Investment demand
Agriculture	0.32	0.27	0.47	0.15	0.27	0.17	0.31
Fishing & Forestry	2.67	2.69	2.34	2.89	2.70	-0.20	0.06
Mining	1.42	1.60	1.12	2.55	1.73	-0.25	0.03
Iron Mining	18.06	10.48	21.53	-8.69	2.22	4.33	3.06
Coal Mining	-33.05	-33.28	-32.93	-33.55	-36.70	-58.97	0.34
Crude mineral oils	-0.39	-2.83	1.35	-5.23	-3.99	0.00	0.00
Natural gas excl. Liquefied	-4.22	-13.10	2.68	0.00	-13.11	-17.82	8.94
Food Industry	0.14	0.13	0.18	0.09	0.12	0.08	0.24
Beverage Manufacturing	0.03	0.03	0.01	0.06	0.04	0.03	0.21
Tobacco	-0.18	-0.15	-0.38	0.03	-0.12	-0.11	0.12
Rubber Products Industry	-5.08	-3.95	-5.72	-0.32	-1.50	-0.39	-0.07
Plastic Industry	-1.29	-1.02	-1.73	0.41	-0.42	-0.27	0.01
Textile Industry	-0.56	-0.41	-0.78	-0.03	-0.19	-0.07	0.14
Wood Industry	2.00	2.30	1.81	2.64	2.35	-0.27	0.01
Furniture and Fixture Industry	-0.87	-0.63	-1.14	0.40	-0.20	-0.18	0.07
Pulp and Paper	9.29	5.07	11.02	-5.29	2.49	3.21	2.33
Asphalt Roofing Industry	-1.73	-0.47	-4.87	3.39	0.04	-2.86	-1.72
Paper Box & Bag Industries	0.90	0.62	2.49	-0.94	0.38	1.22	1.00
Other Converted Paper	2.62	1.66	3.63	-0.38	0.70	0.81	0.73
Printing and Publishing	0.61	0.50	1.19	-0.15	0.36	0.45	0.49
Steel	-1.55	-1.60	-1.42	-1.74	-1.51	0.14	0.00
Steel Pipe & Tube Industry	-0.43	-0.44	-0.43	-0.45	-0.46	0.05	0.22
Iron Foundries	-1.01	-1.15	0.66	-3.98	-1.60	1.16	0.97
Non-Ferrous Smelting	5.02	2.60	5.43	1.07	1.58	0.81	0.73

Alumnium Rolling Casting	0.68	0.19	1.21	-1.83	-0.94	0.38	0.00
Copper Rolling Casting	-1.58	-2.14	-1.11	-4.17	-3.18	0.42	0.47
Other Metal Rolling Casting Etc.	2.80	1.78	3.27	-1.12	-0.22	0.37	0.00
Metal Fabricating Industry	-0.81	-0.77	-0.88	-0.68	-0.71	0.00	0.19
Machinery Industry	-1.66	-0.92	-2.03	-0.08	-0.27	-0.13	0.11
Transportation Equipment	-4.36	-3.26	-4.63	-1.84	-2.15	-0.20	0.06
Electrical Products Industry	-4.20	-3.25	-4.41	-0.89	-1.17	-0.06	0.15
Non-Metallic Products Ind.	1.67	0.92	3.85	-1.22	0.15	1.42	1.14
Cement	9.36	4.05	22.68	-25.16	1.89	12.32	8.26
Motor gasoline	-4.26	-4.81	-0.52	-9.32	-5.30	-5.93	2.21
Diesel & fuel oil aviation fuel	-5.01	-5.94	-0.26	-11.88	-6.80	-8.02	2.82
Liquid petroleum gases	-6.77	-14.79	0.37	-28.86	-17.51	-22.55	7.81
Other refined petroleum prod.	-4.41	-5.82	-0.47	-12.05	-7.67	-13.09	2.26
Industrial Chemicals	-8.88	-5.46	-12.53	1.92	-1.64	-2.63	-1.57
Agricultural and Other Chem.	-2.24	-1.38	-3.86	0.38	-0.54	-0.95	-0.44
Chem. Products Industry	-3.13	-2.55	-4.16	0.75	-0.95	-0.60	-0.21
Miscel. Manufacturing	-1.33	-0.82	-1.57	-0.25	-0.37	-0.07	0.14
Construction Industry	0.08	0.08	-0.33	0.23	0.08	-0.26	0.02
Air Transport	0.44	0.34	0.72	0.21	0.31	0.24	0.36
Railway Transp. & Rel. Serv.	0.36	0.35	0.49	0.29	0.34	0.14	0.29
Water Transport & Rel. Serv.	4.49	3.10	6.51	1.85	2.88	2.09	1.59
Truck Transport Industries	0.87	0.98	0.40	1.20	1.00	-0.35	-0.04
Urban Transit System Industry	1.17	1.09	2.57	0.55	1.04	1.03	0.00
Interurban & Rural Transit Syst.	-0.14	0.00	-0.37	0.14	0.06	-0.12	0.11
Other Transport	0.18	0.26	-0.85	0.68	0.29	-0.74	-0.30
Gas Pipelines	-9.81	-11.68	-4.16	-14.35	-11.88	-17.82	4.09
Storage	0.22	0.37	-0.20	0.59	0.38	-0.38	-0.06
Communication	-0.14	-0.10	-0.56	0.07	-0.09	-0.27	0.01

Electric Power	5.65	5.27	13.43	2.37	5.26	8.00	4.01
Other Pipelines	-0.32	-0.32	0.00	0.00	-0.32	-0.59	-0.20
Wholesale Trade	-0.35	-0.22	-1.05	0.10	-0.21	-0.56	-0.18
Retail Trade	-0.12	-0.11	-0.43	0.00	-0.11	-0.19	0.06
Fire	-0.12	-0.11	-0.48	0.03	-0.10	-0.23	0.04
Service to Business	-0.41	-0.33	-0.89	-0.12	-0.30	-0.31	-0.02
Owner Occupied Dwelling	-0.28	-0.28	0.00	0.00	-0.28	-0.28	0.00
Education Service Industry	-0.02	-0.02	-0.36	0.11	-0.02	-0.21	0.05
Health and Social Services	-0.08	-0.07	-0.48	0.08	-0.07	-0.26	0.02
Accommodation and Food	-0.06	-0.02	-0.23	0.06	-0.01	-0.08	0.14
Amusement and Recreation	1.76	1.32	3.56	0.49	1.17	1.34	1.08
Personal and Misc. Serv.	-0.17	-0.14	-0.68	0.06	-0.13	-0.35	-0.04
Federal Prov. & Terr. Gov.	0.02	0.02	-0.36	0.16	0.02	-0.24	0.03

Table 5: Distribution of *per capita* total expenditures in 2004 Canada ($CAD)

Intervals of *per capita* total expenditures	Population shares	Average expenditures *per capita* in the interval
0 - 5000	0.020	3833
5000 - 10000	0.178	7975
10000 - 15000	0.300	12471
15000 - 20000	0.216	17251
20000 - 25000	0.118	22253
25000 - 30000	0.071	27236
30000 +	0.098	41760
Total population	1.000	17597

Table 6: Intervals (in $CAD) over which row policies statistically dominate column policies

	First order			Second order		
	UCS	RPT	OBA	UCS	RPT	OBA
UCS	—	[0, 18600]	$[0, \infty[$	—	$[0, \infty[$	$[0, \infty[$
RPT		—	$[0, \infty[$	—	—	$[0, \infty[$
OBA	—	—	—	—	—	—

Table 7: Impact of GHG mitigation policies on inequality

Distributions	Gini	Standard error	Confidence interval (95%)	
			Lower	Upper
Initial	0.29619	0.00329	0.28974	0.30265
UCS	0.29627	0.0033	0.28981	0.30273
OBA	0.29703	0.0033	0.29056	0.30350
RPT	0.29708	0.0033	0.29061	0.30355
	Difference	STD	Confidence interval (95%)	
UCS-Initial	0.00008	0.00006	-0.00003	0.00019
OBA-Initial	0.00083	0.00005	0.00074	0.00092
RPT-Initial	0.00088	0.00007	0.00075	0.00102

Table 8: The impact of price changes on the Gini index, by scenario and by group of goods and income sources

	UCS	RPT	OBA
Food	-0.0002	0.0000	0.0000
Energy	0.0006	0.0007	0.0006
Other services	0.0000	-0.0003	0.0001
Income	-0.0004	0.0004	0.0001
Total	0.0000	0.0008	0.0008

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