Regional Burden Sharing of Carbon Mitigation Cost and Output-Based Allocation of Emissions*

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Very preliminary version. Comments are welcome.

Abstract

The issue of fair burden sharing among countries or regions is at the core of discussions surrounding the implementation of environmental agreements. In the context of a decentralized political system within a federal country, asymmetrical profiles of regional industries may hinder a regional consensus on implementing international environmental agreements. Besides, output-based allocation (OBA) of free permits to firms has been suggested by several authors as a solution to the uneven sectoral distribution of abatement costs in a given economy, at the expense of a high marginal abatement cost though. This paper examines the implications of providing more free permits to the most emissions-intensive region within a politically decentralized federation in the context of an OBA scheme. It develops a two-region multisector intertemporal general equilibrium model with an application to the Canadian economy. The simulation results suggest that the regional permit allocation scheme does have an impact on efficiency in an OBA context. When

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more permits are given to the most emissions-intensive region in an OBA scheme, the marginal abatement cost is higher and more distortions are introduced into the economy. The most emissions-intensive region is hurt more than the less-emissions-intensive region, which benefits from resource reallocation and the substitution towards the non-energy-intensive industry.

1 Introduction

This paper examines the implications of two different regional burden sharing rules in a national carbon mitigation policy with an output-based allocation (OBA) system of free emissions permits. The effectiveness and fair distribution of costs are two factors crucial to the success of any greenhouse gas(GHG) mitigation policy. The issue of fair burden sharing among countries is at the core of discussions surrounding international environmental agreements (IEAs). The implementation of these agreements, however, has been uneven mainly due to the existence of large asymmetries across countries and the free-riding phenomenon, among other reasons.

The above difficulties are also present among regions within a country. In the context of a decentralized political system and of asymmetrical profiles of regional industries, obtaining regional consensus on implementing IEAs can prove difficult. As mentioned in Boucekkine et al (2010), the case of Belgium's two regions, Wallonia and Flanders illustrates well the difficulty of reaching an agreement on the burden sharing rules of GHG abatement cost within a single country. A similar regional burden sharing debate has emerged within the Canadian context, where the implementation of IEAs requires the cooperation of provinces, which have shared jurisdiction with the federal government over environmental policy.

Canada is a federation that consists of ten provinces with various production structures. Significant differences in the regional distributional impacts can be detrimental to the political acceptability of GHG reduction policies and thereby to their effective implementation. For successful adoption and implementation of a climate policy, the regional heterogeneity of GHG burden costs must be thoroughly investigated.

Several papers have analyzed the impact of regional burden sharing. Torvanger and Ringius (2002) examined regional heterogeneity impacts using a game theoretic model subject to a common constraint upon the joint strategy space. Arif and Dissou (2010), Böhringer, et al. (2003), Jaccard et al. (2004), Germain et al. (2006), Snoddon & Wigle (2007) and Jaccard & Rivers (2007) are some other examples of studies on the subject. In particular, Snoddon & Wigle (2007) showed that a unilateral regional policy is relatively ineffective when regional regulations are subject to additional leakage that may cause energy prices to fall in the rest of the country. The existing studies have considered a lump-transfer of the permit proceeds to households.

Yet, within a given jurisdiction, the uneven sectoral distribution of abatement costs is a frequently encountered issue that can hamper the political feasibility of carbon mitigation policies. One approach suggested in the literature to address this issue is output-based allocation of free permits to firms. See Bernard, Fischer, and Fox (2007), Böhringer et al (2005) , and Dissou (2006), for interesting discussions on the mechanisms involved in an OBA system. In this system, firms are given free permits according to their current output and emissions intensity as assigned by the regulator. While the permit price compels firms to reduce the use of fossil fuels, the free permits received give firms a strong incentive to enact larger reductions in emissions intensity and, at the same time, experience lower output contractions (Fischer, 2001). This is because the OBA system of emissions permits provides output subsidies to firms enabling them to avoid large falls in output, employment and investment, while reducing their emissions intensity. The higher the number of free permits distributed, the higher the subsidy rate, and the lower the negative impact of carbon mitigation firms on emissions-intensive industries. To some extent, the OBA system of emissions permits can help mitigate the negative impact of GHG mitigation policies on both output and employment in emissions-intensive industries.

In an OBA system, the number of free permits distributed to firms in a given jurisdiction cannot exceed their emissions rights. This gives rise to the issue of burden sharing, i.e., the distribution among regions of the wealth associated with unabated emissions that would be used to provide subsidies to firms. Each region tends to favor a burden sharing rule that would maximize its share in unabated emissions in order to bear the minimal proportion of the national GHG mitigation cost.

The objective of this paper is to assess the implications of a burden sharing rule that provides more emissions rights to the most emissions-intensive region in a GHG mitigation policy with OBA of free permits to firms. In a study on Belgium, Boucekkine, Krawczyk and Vallée (2010) found that giving fewer emissions entitlements to the most emissions-intensive region may be inefficient when interregional externalities are taken into account. This paper asks whether such conclusion is warranted in the context of an OBA of emissions to firms. Though the OBA system helps mitigate the uneven sectoral distribution of GHG mitigation cost, it has a higher welfare cost due to the higher marginal abatement cost (permit price) induced by the output subsidy. Moreover, because of the higher permit price in an OBA system, firms reduce their emissions intensity and the production of fossil fuels more than in a grand-fathering allocation of permits for example. Given the significant share of fossil fuel production in the most emissions-intensive region, it is not clear whether a burden sharing rule that provides more permits to the most emissions-intensive region would be more beneficial to that region and the whole country.

Various papers have analyzed the implications of several burden sharing rules in a regional context. Most of these rules entail an ex-ante regional distribution of emissions rights. One of these rules is the "regional emissions-based allocation (REBA)" rule according to which the share of each region in the national residual emissions is equal to its share in total initial emissions in a given previous year. However, since effective regional residual emissions do not necessarily coincide with ex-ante regional distribution of emissions rights, some regions may end up being net buyers of emissions from the other regions. This potential wealth transfer from one region to the other, which is inherent to the regional allocation of emissions rights, could be a serious hurdle for the political feasibility of a national GHG mitigation policy in a federation with decentralized power.[1] We avoid this potential problem by considering a burden sharing rule that prevents such regional wealth transfers to take place. As in Arif and Dissou (2010), we consider a burden sharing rule that does not assign any ex-ante entitlements to regions. Instead, regions are assigned scarcity rents related to their local unabated emissions, which can be used for output subsidies to firms in an OBA scheme.

We consider two burden sharing rules. In the first, the number of free permits received by a given firm depends on the residual emissions available in their region. The second rule seeks to provide more emissions rights to the most emissions-intensive region without relying on a given ex-ante regional distribution of emissions rights. In this simulation,

[1]It is interesting to recall that the potential wealth transfer from the U.S.to Russia due to the distribution of abatement targets (and,hence of the emissions rights) is one of the reasons behind U.S' withdrawal from the Kyoto protocol.

the regional dimension is discarded in the distribution of free permits. Firms receive free permits, not on the basis of the residual emissions in their respective regions, but on the basis of the residual emissions at the national level. In that context, since the OBA scheme tends to favor emissions-intensive firms, this second scheme would provide more emissions rights to the most emissions-intensive region.

We develop a regional, multi-sector, intertemporal general equilibrium model with endogenous labor supply and pre-existing distortions to examine the impacts of the two above-mentioned burden sharing rules with an application to the Canadian economy. We consider a nationwide permanent 20% reduction in carbon dioxide emissions using a single national permit market. The magnitude of the GHG reduction considered is not related to any actual policy envisaged by the Canadian government. The simulation exercise is meant to derive some useful insights on the potential implications of burden sharing rules in the context of an OBA scheme. These insights could prove useful in the design of an actual GHG mitigation policy in a federation with decentralized power. We are not aware of any study on the impact of regional burden sharing in a dynamic general equilibrium context with an OBA system. The remainder of the paper is as follows. The next section presents the salient features of the model, and Section 3 discusses the data, the parametrization and the solution strategy of the model. The simulation results are discussed in Section 4 and the last section provides some concluding remarks.

2 The model

2.1 The environment

This section presents the main characteristics of a multi-region, multi-sector dynamic general equilibrium model of the Canadian economy designed to analyze the impact of carbon dioxide emissions control policies. The model is built upon the Ramsey optimal growth model in a multi-sector, decentralized competitive equilibrium setting. We consider a deterministic framework since the focus of the analysis is not on fluctuations; hence, uncertainty is ignored. The long-run growth rate of the economy is assumed constant and is determined by the population growth rate and the exogenous Harrod neutral technological progress rate.

Consider a two-region economy with its regions indexed by $r = 1, 2$. Each region consists of households, firms and a fiscal authority (i.e., government). As the model is built to derive high-level insights, we keep the sectoral disaggregation at minimum. A meaningful sectoral disaggregation of a general equilibrium model designed to assess climate change policies should at least account for, on the one hand, energy and non-energy goods producers, and on the other hand, energy-intensive and non-energy intensive industries. Hence, we consider in each region four industries: fossil energy industry (FOS), electricity (ELC) generation industry, energy-intensive industry (EI), and non-energy-intensive industry (NEI)[2]. The non-energy-intensive industry is mostly comprised of the services industry and the non-energy-intensive good producing industries. For this reason, as in most economies, the non-energy-intensive industry is the largest industry in both regions as suggested by data in Table 5. The two regions considered in the model differ mainly by their shares of the fossil fuels industry and energy-intensive industry. Region 1 is considered more fossil-fuels oriented, while Region 2 is more oriented toward the production of energy-intensive goods[3].

All economic agents are assumed to take all prices as given. Households derive satisfaction from the consumption of goods and leisure over an infinite life period and earn income from different sources , including labor and capital returns. They are the owners of the capital stock, which is rented to domestic firms. In each period, they decide on their saving that is used to buy investment goods. They have access to world financial markets and are responsible for the foreign debt that must be paid back at a given world interest rate. Firms produce differentiated goods for the domestic and export markets and decide on the optimal level of labor, intermediate inputs and capital inputs. Goods available in the economy can be used for consumption, investment and intermediate input uses. The fiscal authority collects taxes on production activities, on the transactions of goods and services, and on primary factor incomes. It consumes goods and services and returns balance to households as lump-sum transfers. Without loss of generality, all

[2]It is important to note that energy-intensive and non-energy-intensive industries do not produce energy.

[3]Region 1 includes Alberta,the Prairies Provinces,and the Atlantic Provinces. Region 2 includes the provinces of Quebec, Ontario,British Columbia and the Territories.

variables are expressed per labor efficiency units so as to ignore the exogenous growth effects.[4] In what follows, for notational ease, unless expressly mentioned, we drop the region dimension in the variable and parameter names.

2.2 Household preferences

In each region, there is a finite number of infinitely-lived households that have preferences for consumption goods and leisure. Aggregate consumption is given by the standard constant elasticity of substitution (CES) index of various commodities expressed as:

$$C_t = \left[\sum \theta_i \left(c_{it}\right)^{(\sigma^c-1)/\sigma^c}\right]^{\sigma^c/(\sigma^c-1)} \tag{1}$$

where σ^c and θ_i and are the elasticity of substitution and the share parameter of the household CES function, respectively. This implies that the consumer price index P_t^c and the demand for each commodity, c_{it}, have the following expressions:

$$P_t^c = \left[\sum_i \theta_i \left(p_{it}^h\right)^{1-\sigma^c}\right]^{1/(1-\sigma^c)} \tag{2}$$

$$c_{it} = C_t \left[\frac{\theta_i P_t^c}{p_{it}^h}\right]^{\sigma^c} \tag{3}$$

with p_{it}^h being the consumer prices of individual commodities.

The representative household maximizes an additive intertemporal utility function subject to a sequence of period budget constraints:

[4]Through out the rest of the document, we us e_i for commodities , j for industries (i.e., production activities), t, for time and r (mostly omitted), for regions.

$$
\begin{aligned}
\max\ U_0 &= \sum_{t=0}^{\infty}\left(\frac{1}{1+\rho}\right)^t u(C_t, L_t) \qquad 0<\rho<1, \\
s.t. \quad SAV_t^H &= R_tK_t + w_tL_t + T_t - P_t^cC_t \qquad t = 0,1,..,\infty \qquad (4)\\
u(C_t, L_t) &= \frac{1}{1-\zeta}C_t^{1-\zeta} - \eta\frac{1}{1+\psi}L_t^{1+\psi} \qquad \zeta,\ \psi>0 \qquad (5)
\end{aligned}
$$

SAV_t^H, Rt, Kt, w_t, T_t are, respectively, household saving, the rental rate of capital, the regional capital stock, the wage rate, and government net transfers to households. The parameters, ζ,ψ, and η, are the inverses of, respectively, the intertemporal elasticity of substitution, the labor supply elasticity, and the leisure parameter in the instantaneous utility function. The budget constraint in (4) can be rearranged to include household financial wealth. In reality, household saving and foreign saving, SAV_t^F, are used to fund aggregate gross investment, INV_t, which increases the capital stock.

$$
\begin{aligned}
SAV_t^H + SAV_t^F &= P_t^I INV_t \qquad (6)\\
K_{t+1} &= K_t(1-\delta) + Inv_t \qquad (7)
\end{aligned}
$$

where P_t^I is the index price of investment goods and δ is the depreciation rate of physical capital.[5]

Households hold, in their portfolio, both domestic and foreign assets (liabilities). The domestic assets are represented by the value of domestic capital stock. The return on foreign assets is the exogenous international interest rate, r. In this environment without uncertainty, the following arbitrage condition must hold for households to have both types of assets (domestic and international) in their portfolio.

$$
R_{t+1} = P_{t+1}^I(1-\delta) - (1+r)P_t^I \qquad (8)
$$

[5]Note that aggregate investment is a composite good that does not necessarily have the same composition as aggregate consumption. Its price, P_t^I, needs not necessarily be identical to the consumer price index, P_t^c

The stock of foreign liabilities, B_t, evolves according the following motion equation:

$$B_{t+1} = (1+r)B_t + SAV_t^F \tag{9}$$

Using Expressions (6) and (9), the household period budget constraint (4) can be written as follows.

$$F_{t+1} \quad = F_t(1+r) + \quad w_t L_t + T_t - P_t^c C_t \qquad t = 0, 2, .., \infty \tag{10}$$

where F_t, the household net financial wealth, is defined by: $F_t = P_{t-1}^I K_t - B_t$. Expression (10) can also be seen as the economy-wide budget constraint.

Imposing a transversality condition, the maximisation of the household intertemporal utility function subject to the sequence of period budget constraints (10) yields the following first-order conditions for the choices of aggregate consumption, C_t, labor supply, L_t, and asset holding F_{t+1}:

$$\begin{aligned}
\left(\frac{1}{1+\rho}\right)^t u_{C_t} &= \lambda_t P_t^C && (11)\\
\left(\frac{1}{1+\rho}\right)^t u_{L_t} &= \lambda_t w_t L_t && (12)\\
\lambda_t &= \lambda_{t+1}(1+r) && (13)\\
F_{t+1} &= F_t(1+r) + w_t L_t + T_t - P_t^c C_t && (14)
\end{aligned}$$

where λ_t is the marginal utility of consumption. Equations (11) and (13) can be manipulated to obtain the traditional Euler equation that gives the motion equation of aggregate consumption between two consecutive periods. The Euler equation can be combined with the period budget constraint (14) and the transversality conditions to determine the level of consumption in each period. Given the current wage rate, household labor supply can be determined using the first-order conditions of the household intertemporal problem (11 and 12), which requires that the marginal rate of substitution between consumption and leisure be equal to the ratio of wage rate to the consumption price index.

Finally, the aggregate investment good bought by households is a Cobb-Douglas composite of individual commodities that are used for investment. It follows that the index price of the investment good, P_t^I and the demand for each commodity for investment purposes, $dinv_{it}$ have the following expressions:

$$P_t^I = \prod \left[\frac{p_{it}^v}{\beta_i}\right]^{\beta_i} \tag{15}$$

$$dinv_{it} = \gamma_i \frac{P_t^I INV_t}{p_{it}^v} \tag{16}$$

where p_{it}^v and γ_i are, respectively, the purchase prices of investment goods and the share of each good in total investment.[6]

2.3 Firms and production

The production sector features perfect competition and flexible prices; all firms consider output and factor prices as given. In each industry, firms combine labor, capital and intermediate inputs to produce a composite good. Since the capital stock is owned by households and is rented in each period, the firm's problem can be solved as a standard static optimization problem. The representative firm in each industry sets its price equal to the marginal cost and finds the optimal level of inputs given the level of output determined by demand.

The production function is assumed weakly separable to allow for substitution among inputs. The separability assumption entails the partition of the input set into several subsets whose elements are combined to produce various input indexes through sub-production functions. Gross output, y_{jt}, is a CES function of the index of value-added-energy, VAE_{jt}, and of INT_{jt}, which is the Leontief index of energy and non-energy goods used as intermediate inputs. The index of value-added-energy is a CES aggregate

[6] Investment and consumer goods are not bought at the same price because of the differences in the user tax rates observed in the benchmark data.

of the index of value-added, VA_{jt} , and the index of energy inputs E_{jt}. Capital, k_{jt}, and labor, l_{jt}, are combined to produce the index of value-added using Cobb-Douglas technology.The energy composite is a CES aggregate of electricity and fossil fuels inputs, v_{ijt}, $(i = ELC, FOS)$. Production activities are subject to a production tax t^y_j.

With the constant-returns-to-scale technology, firms set their price equal to the marginal cost and determine the optimal levels of input uses through a cost-minimization rule. The weak separability property of production makes it possible to use a stepwise approach (at all levels of the production process) to find the optimal decisions of the firm. At the top level,cost minimization in the gross output production function gives the marginal cost of the firm, which is set equal to the gross output price (net of production taxes), $p^y_{jt}(1 - t^y_j)$. The optimal levels of of the indexes, VAE_{jt} and INT_{jt} , are consequently determined as below:

$$p^y_{jt}(1 - t^y_j) = \left[\alpha^v_j \left(P^{VAE}_{jt}\right)^{1-\sigma^y_j} + (1 - \alpha^v_j) \left(P^{INT}_{jt}\right)^{1-\sigma^y_j}\right]^{1/(1-\sigma^y_j)} \quad (17)$$

$$VAE_{jt} = y_{jt} \left[\frac{\alpha^v_j \left(1 - t^y_j\right) p^y_{jt}}{P^{VAE}_{jt}}\right]^{\sigma^y_j} \quad (18)$$

$$INT_{jt} = y_{jt} \left[\frac{\left(1 - \alpha^v_j\right) \left(1 - t^y_j\right) p^y_{jt}}{P^{INT}_{jt}}\right]^{\sigma^y_j} \quad (19)$$

where P^{VAE}_{jt}, P^{INT}_{jt}, σ^y_j, and α^v_j are, respectively, the index prices of VAE_{jt}, INT_{jt}, the elasticity of substitution and the share parameters in the gross output production function.

Repeating the same procedures for the sub-production functions makes it possible to determine the input demands for capital, labor, and the demand for commodity i, as intermediate input by industry j, v_{ijt} (i=ELC, FOS, EI, NEI). It is interesting to note that the cascading effect of any input price increase toward the marginal production cost of gross output. An increase in the fossil fuel price through a carbon tax or a permit price, will increase the dual price of total energy used by the firm which will in turn, drive the marginal cost upward. The extent of the ultimate increase in the marginal cost of output will depend, among other things, on the ease of substitution among various inputs in the whole production function.

2.4 Government, trade and equilibrium conditions

The government consumes goods and services, g_{it}, which are assumed to grow at the exogenous growth rate of the economy and thus, remain constant in per labor efficiency units. It derives revenue from production taxes (t_j^y), consumption taxes (t_i^c),taxes on investment goods (t_i^{inv}) and taxes on imports from the rest of the world (t_i^m) . The difference between its revenue and its outlays is returned to households as lump-sum transfers.

On the trade side, we introduce product differentiation between goods according to their origins on the demand side and their destination on the supply side. As a result, in each region, total domestic demand for each commodity, xtd_{it}, is a CES composite of domestically-produced goods, xdd_{it}, and the aggregate of imports, M_{it}^T. The latter variable is another CES function of imports from the other region, m_{it}^{reg}, and imports from the rest of the world, m_{it}^{row}. Total domestic demand for each commodity consists of the quantities demanded for household, c_{it}, and government consumption, g_{it}, investment, $dinv_{it}$, and intermediate inputs, v_{ijt}. A cost-minimization rule makes it possible to determine the demand for each commodity according to its origin . On the supply side, gross output is a constant elasticity of transformation (CET) composite of domestic sales, xds_{it}, and total exports, EX_{it}^T. The latter is also a CET composite of exports to the other region, ex_{it}^{reg}, and exports to the rest of the world, ex_{it}^{row} . The representative firm in each industry determines the optimal deliveries in each market by maximizing the revenue from the sales of their gross output subject to the technological constraint represented by the CET function. On the interregional trade side, the prices of import and export goods must adjust to clear the bilateral trade of goods among the two regions. Finally, foreign saving in each region is the difference between the values of imports and exports plus household transfers abroad.

A competitive equilibrium of this model economy is represented by the price vectors:

- $\left\{P_t^c, P_t^I, P_{jt}^{VAE}, P_{jt}^{INT}, P_{jt}^{VA}, P_{jt}^{ET}\right\}_{t=0}^{\infty}$
- $\left\{p_{jt}^y, p_{it}^h, p_{it}^v, p_{it}^d, p_{it}^{exreg}, p_{it}^{mreg}, w_t, R_t\right\}_{t=0}^{\infty}$,

and the quantity vectors:

- $\{C_t, L_t, K_t, INV_t, VAE_{jt}, INT_{jt}, VA_{jt}, ET_{jt}, M_{it}^T, EX_{it}^T\}_{t=0}^{\infty}$
- $\{y_{jt}, c_{it}^h, dinv_{it}, v_{ijt}, g_{it}, l_{jt}, k_{jt}, ex_{it}^{reg}, ex_{it}^{row} m_{it}^{reg}, m_{it}^{row}\}_{t=0}^{\infty}$

such that in each region and in each period:

1. Households maximize intertemporal utility;
2. Firms maximize profits; and,
3. Prices adjust to clear the domestic and bilateral trade markets of goods as well as the labor and capital markets.

2.5 Emissions and permits allocation rule

The model tracks only carbon dioxide emissions which are in fixed proportion to the total use of commodities in production activities or consumption. We consider a binding national cap on emissions where emitters of carbon dioxide from both regions must buy permits in a single national market. The price of the permit increases the cost of the dirty inputs and induces agents to reduce their use. Besides, the free permit given to firms according to their current output provides incentives not to reduce their output, but to reduce their emissions intensity instead. The following general modeling strategy can provide a good understanding of the emissions reduction policy within an OBA scheme. For notational ease, the time dimension is removed.

Let us denote by y_{jr}, p_{jr}, x_{ijr}, and w_{ir}, the output quantity and price in industry j of region r, and the quantity and the price of input i used by industry j located in region r. Let τ, e_i ($e_i \geq 0$), $\beta_j(\beta_j > 0)$, represent, respectively, the permit price (in \$ per unit of carbon dioxide, i.e., CO_2), the emissions factor associated with input i, and the emissions intensity, i.e., the ratio of emissions to gross output in industry j.[7] Assuming the existence of a concave production function ($y_j = f(x_{ij})$) the firm's profit maximization problem can be stated as follows:

[7]($e_i = 0$ when zero emission is attached to the use of a commodity)

$$\underset{x_{ijr}}{Max}\,\pi_j = p_{jr}y_{jr} - \sum_i w_{ir}x_{ijr} - \tau e_i x_{ijr} + \tau\beta_{jr}y_{jr} \tag{20}$$

The third term in the right-hand side of (20) is the cost of permits and the last term is the value of free permits that depends on the level of output y_{jr} and the emissions intensity of industry j located in Region r. The profit maximization problem can also be written as:

$$\underset{x_{ijr}}{Max}\,\pi_j = (p_{jr} + \tau\beta_{jr})y_{jr} - \sum_i (w_{ir} + \tau e_i)x_{ijr} \tag{21}$$

It is easy to see that the permit price increases the cost of the dirty input (when $e_i > 0$) and the value of the free permits represents an output subsidy to the firm. The higher the emissions intensity, the larger the subsidy rate. At the optimum, the firm will use input I up to the point where:

$$(p_{jr} + \tau\beta_{jr})\frac{\partial f}{\partial x_{ijr}} = w_{ir} + \tau e_i \tag{22}$$

In a binding cap-and-trade system, and abstracting from household emissions for ease of exposition, the permit price is determined endogenously by the equation:

$$\sum_i \sum_j \sum_r e_i x_{ijr} = \overline{E}$$

where $\overline{E}$ is the national cap on emissions.

The regulator cannot distribute more permits than the available amount. It must respect an adding-up restriction which requires that the total number of free permits distributed equals the number of available permits. As the level of output is endogenous, the emissions intensity used to calculate the number of free permits, must also be endogenous, β_{jr}, and hence is called the effective emissions intensity. We assume that the effective emissions intensity is the product of the observed emissions intensity in the benchmark, $\bar{\beta}_{jr}$ and an adjustment factor λ_r: $\beta_{jr} = \lambda_r\bar{\beta}_{jr}$. Since the cap must be observed in each period, permit banking or borrowing is not allowed. In each period, the emissions intensity must therefore be modified uniformly by the endogenous adjustment factor so as to respect the adding-up restriction. The adjustment factor is determined on a regional basis in the first simulation and on a national basis in the second. In the latter simulation, the adjustment factor is uniform across regions ($\lambda_r = \lambda$).

The adding-up restrictions in the first and second simulations are, respectively:

$$\lambda_r \sum_j \bar{\beta}_{jr} y_{jr} = \widetilde{E}_r \tag{23}$$

$$\sum_j \sum_r \lambda \bar{\beta}_{jr} y_{jr} = \overline{E} \tag{24}$$

where $\widetilde{E}_r$ is the level of residual emissions in region r and $\sum_r \widetilde{E}_r = \overline{E}$.

3 Data and parametrization

This section discusses the sources of data used in the study and the calibration of the structural parameters of the model that characterize household preferences, production technology and tax parameters. The model has been calibrated using annual aggregate and sectoral data for two pre-defined Canadian regions. Region 1 consists of the Prairies Provinces, Atlantic Provinces and Alberta, while Region 2 consists of the provinces of Ontario, Quebec, British Columbia and the Territories.

The sectoral disaggregation in the model includes four industries: electricity generation, fossil fuels, energy-intensive industries, and non-energy-intensive industries. Tables 1-2 provide an overview of the sectoral and regional breakdown in the model. Social account matrices (SAM) of both regions have been constructed for the year 2004 using national accounts data, and a tailored version of the input-output tables of the Canadian provinces. These tables provide an interesting disaggregation of the manufacturing sector at the cost of a small regional disaggregation to respect data confidentiality. The SAM also contains data on interregional trade of each commodity as well as on trade activities of each region with the rest of the world.

Data on regional carbon dioxide emissions from the use of fossil fuels by each industry and households in the base year has been used to compute the emissions factors of each commodity. Given the current disaggregation in the model, the use of fossil fuel only releases carbon dioxide emissions in the atmosphere. Tables 1-5 present some main sectoral characteristics of the two regions that we derived using a special version of the Input-Output tables of the Canadian provinces for the year 2004, which provide a richer disaggregation of the manufacturing sector at the cost of regional disaggregation. These tables show that Region 1 is more energy dependent than Region 2, as the shares of energy producing industries in GDP at factor cost is larger in the former region than in the latter. Moreover, industries in Region 1 are more energy-intensive than their counterparts in Region 2, i.e., the shares of energy uses (electricity and fossil) in total production cost are higher in Region 1 than in Region 2.

Data in Table 3 show the importance of interregional trade among the two regions. A non-negligible share of the total exports of each product is sold to the other region. This data points to the error in assuming that each region orients all their exports to the rest of the world.

Entries in Table 6 report the values of external parameters drawn from the literature. The same values of the deep behavioral and technological parameters have been used for both regions. Although the substitution elasticities are the same in the two regions, their production technologies are not identical as industries differ by their input cost shares. This is also valid for the final demand components in both regions.

As discussed earlier, we abstract from the long-run exogenous growth of the economy and focus our attention on per-efficiency variables. We set the steady-state annual world interest rate to 0.05, which implies a discount factor of 0.952 in the household intertemporal utility function. Referring to xx, the inverse of the intertemporal elasticity of substitution is set to 2. In the same vein, the value of 0.95 represents the inverse of the elasticity of labor supply as in xx. Since the household time endowment is normalized to unity, we chose 0.6 as the value of labor supply in the steady state, which represents the average labor participation rate in the labor market. As is common in the literature, the value of 0.1 denotes the annual rate of depreciation of physical capital, and was used to calibrate the total stock of capital in each region in the steady state.

We rely on the estimates used in Okagawa and Ban (2008) for the elasticities of substitution in the CES production function and the CES utility function as shown in Table 6. All index prices and the commodity prices (net of taxes) are set to unity and the values of most of the quantity variables in the model have been calibrated accordingly using the data in the SAM. The tax rates (direct and indirect) were calibrated using tax information provided by the SAM and the calibrated values of the quantity variables. Finally, using the calibrated values of gross output and total emissions in each industry, the sectoral emissions intensities in each industry and each region were calculated.

Relying on the methodologies familiar to the static and dynamic general equilibrium literature, the remaining behavioral parameters were calibrated. Namely, the external behavioral parameters were used in conjunction with the first-order and steady state conditions to recover the share parameters in the utility and production functions. The calibration was performed to generate the dynamic path of endogenous variables so as to reproduce the observed equilibrium in the steady state.

4 Simulations

4.1 Simulation description

We run two simulations with OBA of permits to firms. In both simulations, we reduce the total level of CO_2 emissions in the country by 20% using a national cap-and-trade system. All users of fossil fuels incur the cost of emissions permits, which can be bought in a single national permit market. Households in each region receive a proportion of the permit proceeds that represent their share in total emissions in the benchmark. The remainder of the permit proceeds is distributed to firms free of charge using an OBA mechanism.

The difference between the two simulations pertains to the number of permits distributed in each region. As discussed earlier, the number of free permits received (hence, the subsidies) by each industry depends on the level of current output, and on the assigned sectoral emissions intensity, i.e., the assigned ratio of sectoral emissions to output. The higher is the assigned emissions intensity in a given industry, the higher is the subsidy rate. We assumed that the assigned emissions intensities are identical to the ones observed in the benchmark. Still, as the level of output is endogenous, it is important to impose an adding-up restriction, which requires that the total number of free permits distributed equals the number of available permits.

Since the cap must be observed in each period, we do not allow for permit banking and borrowing. In each period, the emissions intensity must therefore be modified uniformly by an endogenous adjustment factor so as to respect the adding up restriction. The adjustment factor is determined on a regional or national basis depending on the OBA scheme under consideration.

In the first simulation, each region is assigned the level of unabated emissions in their jurisdiction to recycle locally using the OBA scheme. In the second simulation, we consider an allocation scheme that gives more permits to the most emissions-intensive regions and fewer to the other regions under the OBA scheme. Instead of distributing free permits to firms based on the residual emissions in their respective region, the distribution is based on the national residual emissions. In this context, as the number of free permits is based on emissions intensity, emissions-intensive firms (hence, the emissions-intensive regions) receive a higher proportion of free permits.

Unless, otherwise mentioned, all the results presented are expressed as percentage deviations from their benchmark values. We consider as policy instrument a national carbon market that equalizes marginal abatement costs between the two regions. Under the cap, the carbon price is reflected in the permit prices. In what follows, we focus our discussions on the long-run impact of the policies instead of their short-run effects. The short and the long run refer to, respectively, the first year after the shock and the 50th year of simulation during which the steady state is attained. We discuss the results and the mechanisms at play in the first simulation and provide intuitive explanations for the observed changes in the second simulation. We present the graphs of selected variables to depict their transitional dynamics toward a new steady state.

4.2 Simulation 1: Output-based allocation of emissions permits on a regional basis

In this simulation, we consider a neutral allocation of permits to regions that the regional government distributes to the firms in their jurisdiction on an output basis. The number of free permits received by firms in this simulation depends on the level of residual emissions in their respective region. Each region is assigned the level of residual emissions in their jurisdiction. In other words, the level of the emissions intensity adjustment factor depends on the level of unabated emissions in each region.

Graphs 1-5 show the evolution of selected aggregate variables. We observe that the economy reaches a new steady state around the 30^{th} year. In the long-run, the equilibrium permit price for achieving a 20% reduction in total emissions in both regions (i.e., in the country as a whole) is \$59.5 per ton of CO_2. Total emissions (of industries and households) fall in Regions 1 and 2 by, respectively, 23.1% and 16.9%. Region 1 achieves a larger reduction in emissions than Region 2 as the former is more emissions-intensive and incurs a lower abatement cost.

The total value of output subsidies distributed to firms in the country is split between Region 1 and Region 2 in the proportions of 51.2% and 48.8%,respectively. These shares reflect the distribution of regional residual industrial emissions following the imposition of the cap. As the permit price increases the cost of fossil fuels, firms and households reduce their use of fossil fuels and substitute with electricity. The rise in the cost of energy increases production costs in all industries, which leads to a fall in the demand for their products. Gross output falls in all industries and in both regions in the long-run as suggested by results in Tables 8-9.

Still, output falls more in the energy producing industries (i.e., fossil fuels and electricity) than in the other non-energy-producing industries. As an illustration, in Region 1, output falls by 14.0 and 1.1% respectively, in the fossil fuel industry and the non-energy-intensive industry. In each region, output contraction is less severe in the electricity generation industry than in the fossil fuels industry, since the former benefits more from the substitution away from fossil fuels induced by a cap on emissions. However, it is important to note that the declines in output observed in the fossil fuels and the energy-intensive industries are larger in Region 2 compared with Region 1. The reason for this is the relatively low emissions-intensity of industries in Region 2. Consequently, industries in Region 2 receive fewer output subsidies. Hence, the firms in fossil fuels and energy-intensive industries located in Region 2 see larger reductions in output than those in Region 1.

In the long run, the decline in output leads to a fall in the demand for labor and physical capital. The wage rate and the rental rate of capital fall in both regions as shown in Table 7. The change in the rental rate of capital is not surprising despite the household's access to the world financial market. A look at the arbitrage condition requiring households to hold both domestic and foreign assets (Eq. 8) reveals that the rental rate of capital is linked to the constant world interest rate and the price of the investment good. A change in the price of the investment good has an impact on the rental rate of capital. As expected, the fall in the returns to primary factors is more pronounced in Region 1 than in Region 2, as suggested by the results in Table 7. For example, the wage rate declines in the long run by 1.16% in Region 1 versus 0.13% in Region 2.

GDP at market prices declines in both Region 1 and Region 2 starting from the first period and eventually stabilizes in the long-run at 3.0 and 1.6% below its benchmark value, respectively. The decline in the returns to labor and capital in both regions does not exclusively occur in the long-run. It occurs in all periods. These changes lead to a fall in household total permanent income, and consequently, in their aggregate consumption and investment. Aggregate consumption falls in Region 1 by 2.3% vs. 2.1% in Region 2, in the long run.

At first sight, the difference in the magnitudes of the long-run changes in consumption between the two regions is not comparable to those in their GDP. This result is understandable in light of the fact that aggregate consumption does not depend on current income, but on permanent income. Households in both regions tend to smooth their consumption. In contrast, investment in physical capital falls more significantly in Region 1 than in Region 2 by, respectively, -5.1 and -1.9%. Abstracting from the benefits of a low level of emissions, the decline in aggregate consumption translates into a loss in welfare of -2.25 and 2.09% in Region 1 and Region 2, respectively.[8] As expected, the welfare cost is higher in Region 1 than in Region 2.

4.3 Simulation 2: Output-based allocation of emissions permits on a national basis

In the second simulation, we analyze the implications of an OBA permit allocation scheme that endows more permits to the most emissions-intensive region. There are different ways to give free permits to a region. We consider a particular case which implicitly assigns more permits to the emissions-intensive region. In the scheme considered in this simulation, the regional dimension is no longer relevant in the distribution of free permits to firms. The permits are distributed to firms on a national basis. Firms in a given region are no longer constrained by the available permits in their respective region. As a consequence, the adjustment factor of the emissions-intensity is now identical in both regions since the adding-up constraint must now be respected at the national level. As explained earlier, because firms in Region 1 are more emissions-intensive than those in Region 2, they are expected to receive a larger share of the free permits than firms in Region 2. Hence, Region 1 receives more permits than Region 2 under the current scheme.

A straightforward implication of giving more permits to the more emissions-intensive region under an OBA scheme is a higher permit price due to the higher level of subsidies received by the most emissions-intensive firms. The simulation results in Table 7 confirm this intuition; the share of output subsidies received by firms in Region 1 is now 53.0 % vs. 51.2% in Simulation 1. The adjustment factor of emissions intensities increases in Region 1 from 0.81 to 0.83, while it falls in Region 2 from 0.86 to 0.83. As the level of the output subsidy depends on the effective emissions-intensity ($\beta_{jr}\lambda_r$),firms in Region 2 receive fewer permits when these are distributed on a national basis instead of on a regional basis. As expected, the permit price in this simulation is higher \$52.6 vs. \$52.1 per ton of CO_2 recorded in the previous simulation.

[8]The measure of welfare change is the percentage change in the benchmark aggregate consumption that would yield the same level of utility as after the reform.

The combination of a higher permit price and lower output subsidies induces firms in Region 2 to enact slightly larger reductions in emissions compared with Simulation 1. The opposite case is observed for firms in Region 1 which enact lower emissions reductions in comparison to the previous simulation. The higher permit price induces a larger reduction in the use of fossil fuels whose production falls more in both regions than in the previous simulation. This fall, however, is more detrimental to Region 1 than to Region 2 as the share of fossil fuels in production in the former region is more significant than in the latter.

Moreover, as the cost of fossil fuels increases, energy-intensive industries see their output fall and resources move toward the other sectors. In Region 1, the electricity generation industry is the beneficiary of the resource reallocation as its output declines less than in the previous simulation in the long-run. In contrast, in Region 2, the non-energy-intensive industry is the main beneficiary of the sectoral shift of resources. As an illustration of these resource reallocation effects, the fall of gross output in the electricity generation industry in Region 1 amounts to -2.0% compared with -3.4% in the previous simulation, in the long-run. In Region 2, gross output falls in the non-energy-intensive industry by about -1.3% in both simulation 1 and 2.

Given the sectoral distribution of GDP at factor cost in each region, the results in Table 7 suggest that Region 2 benefits more from the scheme imposed in simulation 2 than Region 1. This is because the impacts of the new scheme of OBA of permits are less acute in Region 2 than in Region 1. This result occurs, despite the fact that Region 1 receives a larger share of output subsidies than Region 2 in the current simulation. In the long-run, in Region 1, GDP at market prices falls by 3.29% compared with 3.03% in the first simulation. In contrast, Region 2 experiences a lower decrease in its GDP at market prices, -1.55% vs. -1.63% in, respectively, Simulations 2 and 1.

The main reason for this is that the higher permit price induced by the OBA scheme magnifies the distortions created by the permit price, and induces users to reduce the use of fossil fuels more so than in the previous simulation. Yet, fossil fuels production is a major production activity in Region 1. In addition, the higher permit price provides incentives to reduce less the production of non-energy-intensive goods in Region 2. Hence, with a higher level of GDP in Simulation 2, Region 2 is able to increase its exports to

Region 1, mainly its exports of non-energy-intensive goods. The higher permit price in the second simulation has a more negative effect on labor supply in Region 1 than in Region 2, which, in the long run, falls by 1.38% compared with 0.99% in the previous simulation. The opposite effect is observed in Region 2, where households decrease their labor supply by 1.27% in the current simulation vs. 1.38% in Simulation 1.

Some GDP components, such as, aggregate consumption, investment and exports follow the same pattern as GDP in both regions. In Region 1, these variables experience stronger declines in this simulation than in the previous, while the opposite phenomenon is observed in Region 2. A direct consequence of lower consumption in Region 1 in this simulation is that the welfare cost of this OBA scheme is larger than the one observed in the previous simulation: -2.38 vs. -2.25. In contrast, in Region 2, households are slightly better off with the OBA scheme chosen for this simulation than in the previous one: -2.08 vs.-2.11.

5 Conclusions

This paper analyzed in an intertemporal framework, the short- and the long-run impacts of regional allocation of emissions permits in a carbon control policy with an output-based allocation scheme. It considered the case of a decentralized federal jurisdiction and used as an example, a stylized representation of the Canadian federation in which the power over environmental regulations is jointly shared between the federal and provincial governments. The Canadian provinces and territories were divided into two regions according to their emissions-intensity: a high emissions-intensive region and a low emissions-intensive region. The production sector in each region was disaggregated into four industries.

A two-region, multisector, intertemporal general equilibrium model of the Canadian economy was developed to derive insights related to a national carbon control policy. Two different schemes of OBA of emissions were considered. In the first scheme, each region was assigned the residual emissions in their jurisdiction that were used to provide free permits to firms through an OBA mechanism. In the second scheme, firms were given free permits using an OBA mechanism that was based on the level of residual emissions available nation-wide. As the most emissions-intensive industries receive proportionally more permits in an OBA context, the latter scheme was supposed to mimic the attribution of more permits to the most emissions-intensive region. As expected, the less-emissions-intensive region was less affected by the carbon control policy. It registered the lowest reduction in economic activity, and, abstracting from the benefits of reduced levels of emissions, its households experienced the lowest reduction in welfare.

The simulation results also suggested that, in an OBA context, the regional permit allocation does have an impact on efficiency. When more permits are given to the most emissions-intensive region, the marginal abatement cost, i.e., the permit price is higher, as a consequence of more output subsidies provided to firms in that region. The increase in the permit price amplifies the reduction in the use of fossil fuels, and hence in their production, in that region, at the benefit of non-energy-intensive goods. Moreover, the increase in the permit price magnifies the distortions and output falls more and households experience a larger reduction in welfare. Consequently, the most emissions-intensive region is hurt more than the less-emissions-intensive region when given more permits in an OBA scheme. Ironically, the resource reallocation and the substitution towards the non-energy-intensive industry benefits more the other, less emissions-intensive region, which is hurt less by the carbon mitigation policy.

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Table 1: Sectoral shares in the Social accounting matrix of Region 1 in the benchmark situation

	Electricity	Fossil fuels	Energy-Intensive	Non-energy-intensive	Consumption	Investment	Exports	Imports
Electricity	0%	1%	2%	1%	2%	0%	1%	0%
Fossil fuels	20%	12%	24%	3%	4%	1%	40%	17%
Energy-Intensive	3%	8%	20%	8%	8%	16%	21%	34%
Non-energy-intensive	15%	15%	20%	38%	77%	81%	39%	49%
Indirect taxes	2%	1%	1%	2%	10%	2%	0%	0%
Value-added	61%	63%	34%	47%				
	100%	100%	100%	100%	100%	100%	100%	100%

Table 2: Sectoral shares in the Social accounting matrix of Region 2 in the benchmark situation

	Electricity	Fossil fuels	Energy-Intensive	Non-energy-intensive	Consumption	Investment	Exports	Imports
Electricity	0%	1%	2%	1%	2%	0%	0%	0%
Fossil fuels	7%	16%	12%	2%	4%	1%	10%	21%
Energy-Intensive	2%	26%	29%	7%	7%	15%	31%	35%
Non-energy-intensive	14%	19%	20%	39%	78%	79%	59%	45%
Indirect taxes	3%	1%	1%	3%	10%	6%	0%	-1%
Value-added	74%	37%	35%	47%				
	100%	100%	100%	100%	100%	100%	100%	100%

Table 3: Trade orientation by region

	Region 1				Region 2			
	Regional exports	Exports to ROW	Regional imports	Imports from the ROW	Regional exports	Exports to ROW	Regional imports	Imports from the ROW
Electricity	47%	53%	32%	68%	6%	94%	38%	62%
Fossil fuels	24%	76%	24%	76%	16%	84%	22%	78%
Energy-Intensive	30%	70%	27%	73%	11%	89%	8%	92%
Non-energy-intensive	39%	61%	60%	40%	19%	81%	16%	84%

Table 4: Shares of carbon dioxide emissions by region in the benchmark

	Region 1	Region 2
Electricity	31%	13%
Fossil fuels	23%	3%
Energy-Intensive	13%	21%
Non-energy-intensive	20%	38%
Households	13%	25%
	100%	100%

Table 5: Sectoral shares in GDP at factor cost

	Region 1	Region 2
Electricity	2%	2%
Fossil fuels	20%	3%
Energy-Intensive	8%	11%
Non-energy-intensive	70%	84%
	100%	100%

Table 6: External behavioral parameters used for the model calibration

	Electricity	Fossil fuels	Energy-Intensive	Non-energy-intensive
Elasticity between value-added-energy and intermediate inputs	0.2	0.2	0.2	0.2
Elasticity between value-added and energy	0.5	0.5	0.5	0.5
Elasticity between fossil fuels and electricity	0.2	0.2	0.2	0.2
Elasticity first level CET	2	2	2	2
Elasticity second level CET	2	2	2	2
Elasticity first level Armington	2	2	2	2
Elasticity second level Armington	2	2	2	2
World interest rate			0.05	
Inverse of labour supply elasticity			0.95	
Inverse of intertemporal elasticity of substitution			2	

Table 7: Long-run impact on selected aggregate variables by region
Percentage deviations from benchmark values unless otherwise mentioned

	Region 1		Region 2	
	Simulation 1	Simulation 2	Simulation 1	Simulation 2
GDP market prices	-3.03	-3.29	-1.63	-1.55
Household consumption	-2.33	-2.45	-2.11	-2.08
Welfare	-2.25	-2.38	-2.09	-2.06
Total investment	-5.11	-5.23	-1.92	-1.89
Total exports	-5.97	-6.29	-3.77	-3.68
Regional exports	-4.73	-4.95	-3.99	-3.91
Exports to the ROW	-6.54	-6.90	-3.73	-3.64
Total imports	-5.34	-5.34	-3.80	-3.84
Regional imports	-3.99	-3.91	-4.73	-4.95
Imports from the ROW	-6.36	-6.41	-3.64	-3.65
Labor supply	-0.99	-1.38	-1.38	-1.27
Wage rate	-1.16	-0.80	-0.13	-0.24
Rental rate of capital	-0.61	-0.47	0.10	0.06
CO_2 Emissions	-23.92	-23.80	-16.09	-16.21
Permit price ($/ton of CO2)	52.10	52.59	52.10	52.59
Share of output subsidies	51.18	53.04	48.82	46.96
Adjustment factor (of emissions intensities)	0.81	0.83	0.86	0.83

Simulation 1: OBA with regional distribution of free permits

Simulation 2: OBA with national distribution of free permits

Table 8: Long-run impact on selected sectoral variables in Region 1
Percentage deviations from benchmark values unless otherwise mentioned

	Electricity		Fossil fuels		Energy-Intensive		Non-energy-intensive	
	Simulation 1	Simulation 2	Simulation 1	Simulation 2	Simulation 1	Simulation 2	Simulation 1	Simulation 2
Gross output	-3.41	-2.00	-13.98	-14.18	-2.44	-2.66	-1.41	-1.73
Value added	15.31	17.09	-12.29	-12.50	-0.48	-0.77	-0.86	-1.21
Labor	15.78	17.37	-11.85	-12.24	-0.27	-0.65	-0.69	-1.10
Capital	15.13	16.98	-12.35	-12.54	-0.83	-0.98	-1.24	-1.43
Energy use	-37.03	-36.21	-21.94	-22.10	-5.57	-5.71	-8.34	-8.48
Fossil fuels use	-37.08	-36.25	-22.28	-22.46	-5.74	-5.91	-9.01	-9.20
Electricity use	-19.54	-18.15	-17.94	-17.86	-3.30	-3.17	-5.16	-5.06
Emissions	-37.08	-36.25	-22.28	-22.46	-5.74	-5.91	-9.01	-9.20
Subsidy as % of total producer price	28.36	29.57	2.74	2.86	2.18	2.28	0.56	0.58
Shares in total output subsidies	36.00	36.40	23.64	23.50	15.83	15.74	24.53	24.36
Total exports	-0.22	3.08	-13.56	-13.76	-2.16	-2.40	-0.25	-0.79
Regional exports	-1.53	0.62	-12.92	-13.07	-2.25	-2.37	-0.58	-0.93
Exports to the Rest of the world	0.94	5.24	-13.76	-13.99	-2.13	-2.41	-0.04	-0.71
Total imports	-7.45	-8.89	-16.51	-16.62	-3.45	-3.59	-2.68	-2.55
Regional imports	-5.59	-6.71	-15.87	-15.96	-3.76	-3.85	-2.34	-2.19
Imports from the Rest of the World	-8.31	-9.90	-16.71	-16.84	-3.34	-3.49	-3.19	-3.08

Simulation 1: OBA with regional distribution of free permits

Simulation 2: OBA with national distribution of free permits

Table 9: Long-run impact on selected sectoral variables in Region 2
Percentage deviations from benchmark values unless otherwise mentioned

	Electricity		Fossil fuels		Energy-Intensive		Non-energy-intensive	
	Simulation 1	Simulation 2	Simulation 1	Simulation 2	Simulation 1	Simulation 2	Simulation 1	Simulation 2
Gross output	-3.34	-3.60	-14.66	-14.73	-3.72	-3.74	-1.36	-1.27
Value added	0.30	0.07	-14.12	-14.17	-2.70	-2.69	-1.04	-0.93
Labor	0.46	0.27	-14.02	-14.03	-2.62	-2.59	-0.97	-0.84
Capital	0.23	-0.03	-14.21	-14.29	-2.84	-2.88	-1.20	-1.14
Energy use	-31.80	-32.15	-16.11	-16.20	-6.89	-6.97	-6.97	-6.97
Fossil fuels use	-31.85	-32.20	-16.17	-16.27	-7.14	-7.22	-7.55	-7.55
Electricity use	-20.37	-20.73	-15.27	-15.38	-5.19	-5.28	-4.59	-4.60
Emissions	-31.85	-32.20	-16.17	-16.27	-7.14	-7.22	-7.55	-7.55
Subsidy as % of total producer price	6.73	6.56	0.69	0.67	1.11	1.08	0.35	0.34
Shares in total output subsidies	17.34	17.30	3.74	3.74	28.16	28.15	50.76	50.81
Total exports	-2.96	-3.61	-15.15	-15.21	-4.13	-4.17	-1.65	-1.47
Regional exports	-5.59	-6.71	-15.87	-15.96	-3.76	-3.85	-2.34	-2.19
Exports to the Rest of the world	-2.79	-3.40	-15.01	-15.07	-4.17	-4.21	-1.49	-1.30
Total imports	-3.04	-2.14	-12.25	-12.34	-2.35	-2.33	-1.03	-1.11
Regional imports	-1.53	0.62	-12.92	-13.07	-2.25	-2.37	-0.58	-0.93
Imports from the Rest of the World	-3.94	-3.79	-12.06	-12.14	-2.36	-2.32	-1.12	-1.15

Simulation 1: OBA with regional distribution of free permits

Simulation 2: OBA with national distribution of free permits

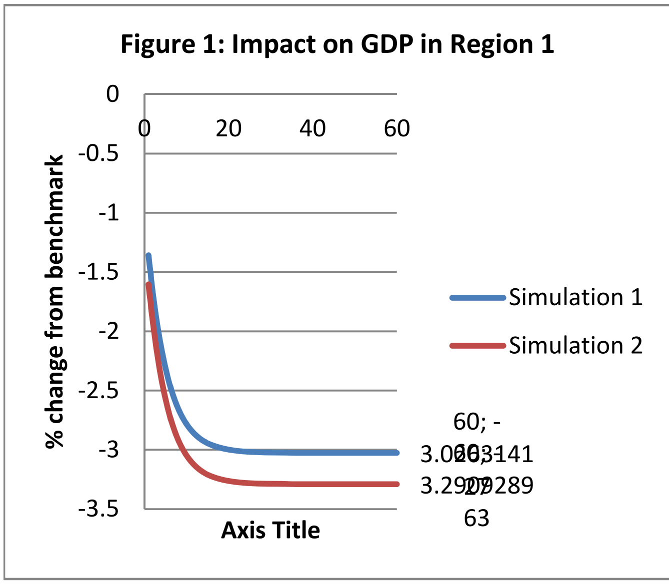

Figure 1: Impact on GDP in Region 1

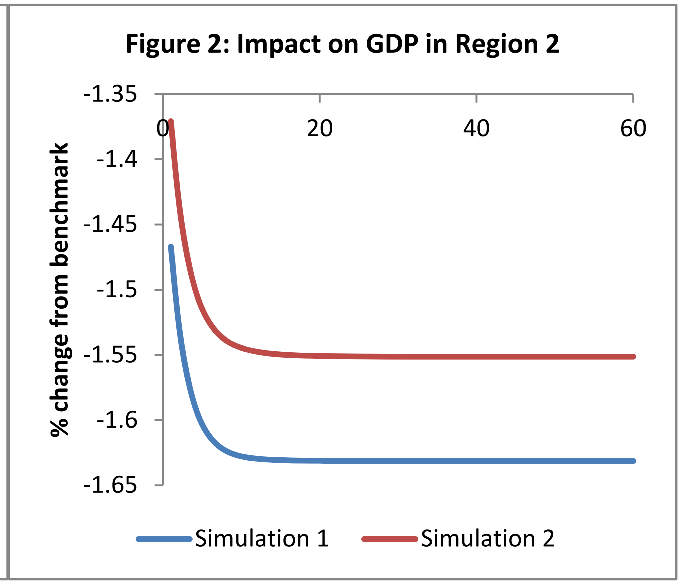

Figure 2: Impact on GDP in Region 2

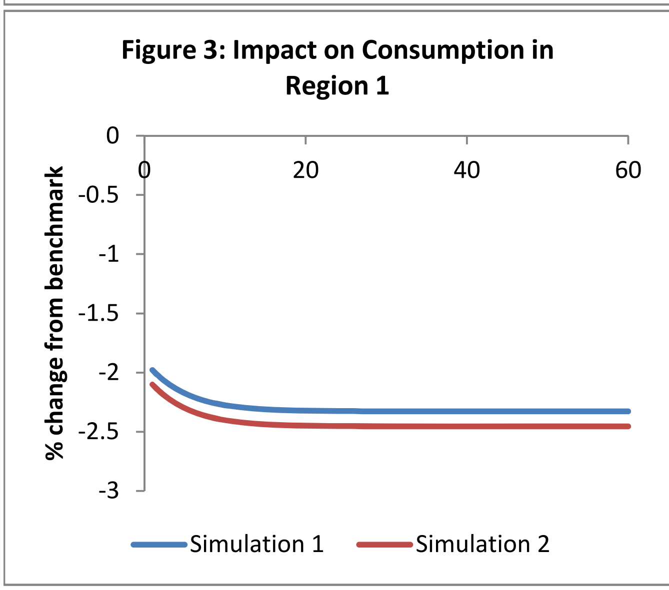

Figure 3: Impact on Consumption in Region 1

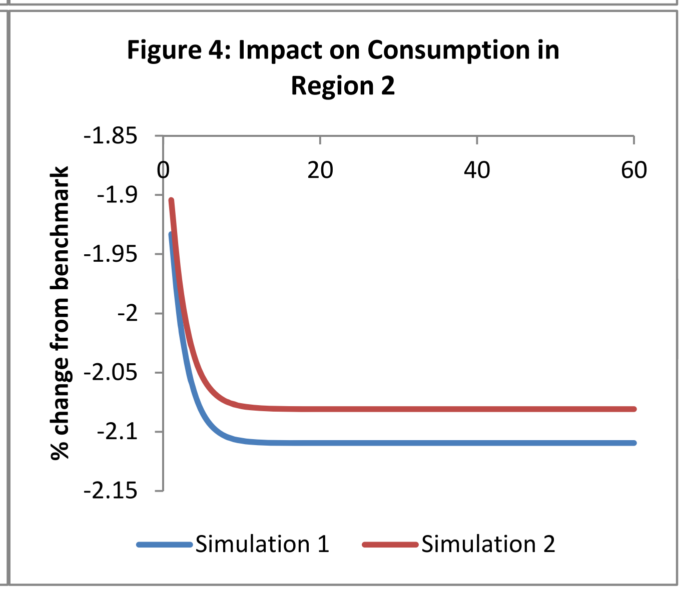

Figure 4: Impact on Consumption in Region 2

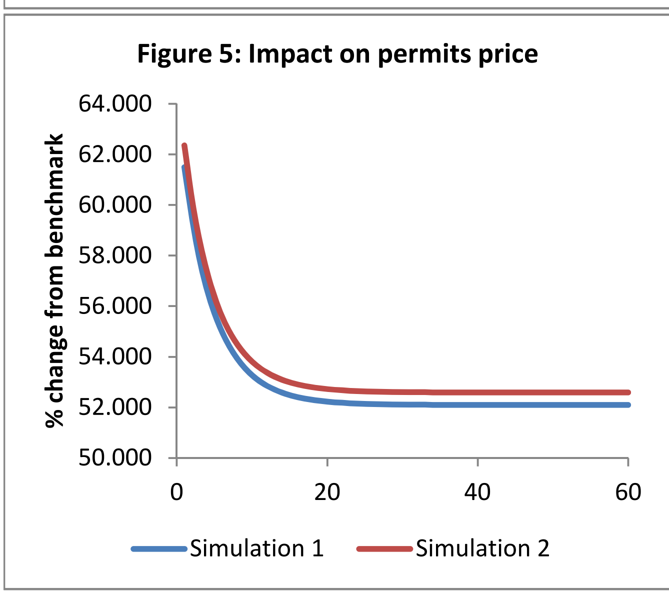

Figure 5: Impact on permits price