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ANALYSIS

Industrial output restriction and the Kyoto protocol: An input–output approach with application to Canada

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ABSTRACT

The objective of this paper is to assess the economic impacts of reducing greenhouse gas emissions by decreasing industrial output in Canada to a level that will meet the target set out in the Kyoto Protocol. The study uses an ecological–economic Input–Output model combining economic components valued in monetary terms with ecologic components – GHG emissions – expressed in physical terms. Economic and greenhouse gas emissions data for Canada are computed in the same sectoral disaggregation. Three policy scenarios are considered: the first one uses the direct emission coefficients to allocate the reduction in industrial output, while the other two use the direct plus indirect emission coefficients. In the first two scenarios, the reduction in industrial sector output is allocated uniformly across sectors while it is allocated to the 12 largest emitting industries in the last one. The estimated impacts indicate that the results vary with the different allocation methods. The third policy scenario, allocation to the 12 largest emitting sectors, is the most cost effective of the three as the impacts of the Kyoto Protocol reduces Gross Domestic Product by 3.1% compared to 24% and 8.1% in the first two scenarios. Computed economic costs should be considered as upper-bounds because the model assumes immediate adjustment to the Kyoto Protocol and because flexibility mechanisms are not incorporated. The resulting upper-bound impact of the third scenario may seem to contradict those who claim that the Kyoto Protocol would place an unbearable burden on the Canadian economy.

1. Introduction

Representatives from more than 160 countries met in Kyoto in 1997 to negotiate emission targets aimed at tackling global climate change. An agreement was reached and resulted in the Kyoto Protocol (KP) establishing emission limits for developed nations – Annex I countries – relative to their 1990 emission levels. The KP took effect after ratification by Russia in late 2004. The agreement now includes industrialized countries that account for at least 55% of total CO_2 emissions from developed nations in 1990 — with the notable exception of the US that did not ratify the Protocol. This enables the Protocol to enter into force and participating nations are committed to a reduction of 5.2% of global greenhouse gas (GHG) emissions compared to 1990 levels by 2012 with different targets for different industrialized countries. For

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example, the emission reduction targets for the European Union was set at 8%, while for Canada the target was 6% below their 1990 level of emissions.

Each nation must implement national policies that will limit GHG emissions. There are several approaches to achieve this objective. One approach would be to promote new technology that decreases the amount of GHG. This could include such things as: increasing the use of energy efficiency equipment, shifting to less carbon-intensive fossil fuels, accelerating the adoption of renewable energy technologies, and switching to best available technologies.

Another approach could be the development of market mechanisms that create the appropriate incentives. This could include such tools as carbon trading at both the national and international levels. Another means of achieving a country's commitment is to take advantage of the flexibility mechanisms that are provided for in the KP. These include the Clean Development Mechanism and Joint Implementation, which allow for GHG reductions in other countries to be counted against the commitment made by another country (IPPC, 2001). Yet another approach is the use of Command-and-Control measures such as fixing emission limits, CO_2 taxes, or limiting industrial output.

Emission restrictions undoubtedly impact the economy of a particular country. Several studies have estimated the impact of satisfying the KP through emissions reduction on a worldwide or national basis (Weyant and Hill, 1999, Nordhaus and Boyer, 1999; Hamaide and Boland, 2000; IPPC, 2001; Cline, 2004, among others). In addition, how policies are introduced will impact the cost of the environmental regulation on the economy. Several studies have shown that targeting environmental policies can provide the same level of environmental benefit at lower costs than a uniform standard (Carpentier et al., 1998; Dissart et al., 2000; Wu and Skelton-Groth, 2002; Lant et al., 2005). Thus, the cost of satisfying a country's KP commitment will depend on the policy selection made by the country and how these policies are implemented.

The current federal government in Canada, lead by Mr. Steven Harper, has been reluctant to implement environmental policies that will meet Canada's KP commitment for the first commitment period. They argue that the economic cost will be too large and have instead instituted policies that will result in GHG emission reductions further into the future. The government introduced their Clean Air Act into Parliament on October 19, 2006 (Canada's Clean Air Act, 2006). The Act addresses both air pollution and GHG emissions in the short term (2010–2015), medium term (2020–2025) and long term (2050). Intensity targets will be set in the short term while absolute reduction in GHG emissions should occur by 2050. Currently there is no national domestic carbon trading mechanism in Canada – however, the previous government had established a set of rules and an institutional structure for carbon trading – and none of the other flexible KP mechanisms have played a significant role in government policy. Finally, several provinces in Canada have developed their own strategies to decrease GHG emissions.

For example, the province of Alberta requires large industries to decrease their emissions by twelve percent and the province has established a carbon trading institution to facilitate this (Government of Alberta, 2007). These efforts, while addressing GHG emission, are however not large enough to meet Canada's KP commitment in the first period.

This paper analyzes the impact on the Canadian economy of satisfying its KP commitment through a reduction in industrial output and shows that the costs vary depending on the initial allocation of industrial sector reductions and the distribution across sectors. Estimating such costs therefore addresses the federal government's concern that meeting the KP commitment is too costly. It also shows impacts on GDP and employment of various scenarios aimed at reducing industrial output for an immediate transition to the KP target. The scenarios take into account different distributions or targeting the reduction in industrial output, i.e. allocate evenly across all industrial sectors or concentrate the reduction to those industrial sectors that are the largest emitters. By concentrating on the reduction in industrial output and not considering the other flexibility mechanisms, the results of the model may be interpreted as an upper-bound cost of the KP.

This study represents a snapshot at one point in time. Hence, it is static rather than dynamic. The purpose is to use available disaggregated data and to quantify the environmental (GHG emission reduction) and economic (cost and employment) impacts of an immediate adjustment to the Canadian Kyoto targets. Rather than proposing optimal annual adjustments or linear adjustments until the end of the first commitment period, which requires the use of extrapolated data for GHG emissions, economic and demographic data, this analysis is based on existing data and the impacts detailed in the following section represent global, non recurring "efforts" to be undertaken. This method, providing an upper-bound cost estimate, has merit because it reduces the uncertainty due to data extrapolation and leaves to the decision-maker the allocation of the emission reductions. Obviously, it has the disadvantage of being a static analysis, unable to determine how the burden should be allocated across time. But as Kyoto policies aim to reach a certain target by a certain date rather than propose an emissions trajectory – requiring a dynamic perspective – a static analysis can provide insight that could assist a decision-maker (Chander et al., 2002).

The remainder of the paper is organized as follows. Section 2 details the ecological–economic I–O model used in this study. Data collection and estimations are discussed in Section 3. The next two sections apply the model to various policy scenarios and provide results. The final section concludes and underlines some important caveats to the analysis.

2. The ecological–economic I–O model

The Input–Output model (I–O) is a general equilibrium model of the economy. Each element of the model represents a monetary flow. When augmented by ecological commodity inputs and outputs in physical units, the I–O framework is an adequate tool to investigate ecological–economic issues, such as climate change policy.

Historically, Cumberland (1966) designed the first I–O table highlighting economic and environmental interactions. A few years later, Leontief (1970) integrated an anti-pollution

Table 1 – The augmented I–O Framework

	Commodities (1 to m)	Industries (1 to n)	Final demand (1 to f)			Total	GHG (1 to z)	Total	
Commodities (1 to m)		**U** u_{ij}	**F** f_{ij}	**GHGF** $ghgf_{ij}$		**q** q_i		**k** k_{ic}	**l** l_i
Industries (1 to n)	**V** v_{ji}					**g** g_j	**GHGI** $ghgi_{jc}$	**h** h_j	
Primary inputs (1 to p)		**YI** yi_{ij}	**YF** yf_{ij}			**n** n_i			
	q' q'_i	**g'** g'_j	**e'** e'_j	**s** s_{jc}	**t** t_j		**r** r_c		

Source: Smith, Statistics Canada, 1991.

industry in his I–O framework to develop a model addressing industrial pollution. For the purpose of this study, the break-through came with Victor (1972) who presented an ecological–economic I–O table combining economic and environmental commodities and introduced economic components in monetary terms while ecological ones were expressed in physical terms.

He utilized the rectangular accounting framework used in the Canadian I–O model to identify the interactions between the economy and the environment. This approach was expanded upon by Carpentier (1994) who increased the number of ecological goods integrated into the accounting framework.

More recently, a growing number of climate change studies have used the I–O framework to analyze this problem. For example, Hetherington (1996) and Labandeira and Labeaga (2002) measured CO_2 intensities for each industrial sector in the United Kingdom and Spain, respectively. Kratena and Schleicher (1999) analyzed the impact of stringent climate change policies for Austria; and Thomassin (2002) measured the impact of mitigation strategies to reduce GHG emissions from Canada's agriculture sector with an I–O model.

The purpose of this paper is to evaluate the impact of a restrictive climate policy that limits industrial output as a means of reducing Canada's GHG emissions to appropriate KP levels. This has an obvious impact on industrial output, GDP, as well as employment. The augmented I–O framework developed by Smith (1991), which uses the Victor (1972) economic–ecological method, is used to estimate the impact of the reduced industrial output.

In this model, Victor's ecological commodities are limited to GHG emissions. As a result, each economic commodity input or output (in monetary unit) is linked to a certain amount of GHG emissions (in physical unit).

The basic commodity-by-industry rectangular I–O framework (Table 1 — dark cells) is defined by five matrices[1]: **V**, the make matrix, **U**, the use matrix, **F**, the final demand matrix, **YI** and **YF**, the primary input matrices; and six vectors: **g**, **q**, **n**, **g'**, **q'** and **e'**, representing respectively total industrial revenue, total commodity demand, total primary inputs and their transposes. All these variables are expressed in monetary terms.

This framework is then augmented by six vectors and two matrices associated with the GHG emissions (Table 1 — light-colored cells) and expressed in physical terms. **GHGI** represents the GHG emission matrix for industrial sectors, where each $ghgi_{jc}$ is the amount of each type of GHG emissions c produced by each industrial sector j; and **GHGF** represents the matrix of GHG emissions for final demand, where each $ghgf_{ij}$ is the amount of each type of GHG emission relative to the total value of each commodity i consumed by each sector of final demand j. Vector **h** is the total amount of GHG emissions produced by each industry j; **k** is the total amount of each type of GHG emission c relative to the total value of each commodity i; **l** is the total amount of GHG emissions relative to each commodity i; **r** is the total amount of each type of GHG emissions c; **s** is the total amount of GHG emission relative to the consumption of all economic commodities by each final demand sector j; and **t** is the total amount of GHG emissions relative to all the sectors of the final demand.

In the I–O model accounting framework, the total industrial revenue for each sector equals the total industrial cost for each sector; vector **g** equals vector **g'**. In addition, the vector of total demand is equal to the value of intermediate demand plus final demand and this is equal to total industrial output; **q'** is equal to **q** (see Table 1). From this accounting framework, the following relationships can be deduced:

$$\mathbf{q} = \mathbf{U}\,\mathbf{i} + \mathbf{F}\,\mathbf{i} \tag{1}$$

$$\mathbf{g} = \mathbf{V}\,\mathbf{i} \tag{2}$$

where **i** is a column vector whose elements are unity.

The present general equilibrium accounting framework is developed under the *industry-based technology* assumption. In other words, all commodities – main products and by-products – of any industry are produced with the same technical production structure. The *input coefficient matrix* **B** can then be defined as follows:

$$\mathbf{B} = \mathbf{U}\,g^{-1} \tag{3}$$

where g represents the diagonal matrix of $\mathbf{g}_{[n\times 1]}$.

[1] The elements of the five matrices are defined as such: each v_{ji} represents the value of commodities i produced by each industrial sector j; each u_{ij} represents the value of commodities i required by each industrial sector j to produce its output; each f_{ij} represents the value of commodities i demanded by each sector j of final demand; each yi_{ij} represents the value of primary inputs i required by each industrial sector j to produce their output and each yf_{ij} represents the value of primary inputs i demanded by each sector j of final demand.

On an annual basis, each industrial sector has a share of the total market for a commodity. This *market share matrix* **D** can be expressed as

$$\mathbf{D} = \mathbf{V}\,\boldsymbol{q}^{-1} \tag{4}$$

where q represents the diagonal matrix of **q**.

After rearranging Eqs. (3) and (4), incorporating these equations respectively into Eqs. (1) and (2) and gathering together both equations, we find

$$\mathbf{U} = \mathbf{B}\,\boldsymbol{g} \tag{3'}$$

$$\mathbf{V} = \mathbf{D}\,\boldsymbol{q} \tag{4'}$$

$$\mathbf{q} = \mathbf{B}(\boldsymbol{g}\,\mathbf{i}) + \mathbf{F}\,\mathbf{i} = \mathbf{B}\,\mathbf{g} + \mathbf{F}\,\mathbf{i} \tag{5}$$

$$\mathbf{g} = \mathbf{D}(\boldsymbol{q}\,\mathbf{i}) = \mathbf{D}\,\mathbf{q}. \tag{6}$$

Inserting Eq. (6) into Eq. (5) and rearranging terms give:

$$\mathbf{q} = (\mathbf{I} - \mathbf{B}\,\mathbf{D})^{-1}\,\mathbf{F}\,\mathbf{i}. \tag{7}$$

Eq. (7) is used to estimate the change in the total production of commodities due to a change in the final demand for commodities. The inverse matrix $(\mathbf{I}-\mathbf{B}\ \mathbf{D})^{-1}$ is in fact the *commodity-by-commodity total requirements* matrix, which expresses the quantity of commodity i required to deliver a dollar's worth of commodity j to final demand. For expressing in terms of industrial output instead of commodity, Eqs. (5) and (6) are arranged as follows:

$$\mathbf{g} = \mathbf{D}\,(\mathbf{B}\,\mathbf{g} + \mathbf{F}\,\mathbf{i}) \tag{8}$$

$$(\mathbf{I} - \mathbf{D}\,\mathbf{B})\,\mathbf{g} = \mathbf{D}\,\mathbf{F}\,\mathbf{i} \tag{9}$$

$$\mathbf{g} = [(\mathbf{I} - \mathbf{D}\,\mathbf{B})^{-1}\,\mathbf{D}]\,\mathbf{F}\,\mathbf{i} \tag{10}$$

The bracketed quantity $[(\mathbf{I}-\mathbf{D}\ \mathbf{B})^{-1}\ \mathbf{D}]$ expresses the dollar's worth of industry i's output required to deliver one dollar's worth of commodity j to final demand. In other words, this *industry-by-commodity total requirements* matrix is used to measure the direct plus indirect impacts on the industrial sectors as a result of a change in commodity final demand.

However, this matrix does not take into account leakages in the economy. Leakages in this model can take three forms: (1) imported goods that satisfy either intermediate or final demand, (2) government production of goods and services, and (3) withdrawals from inventories. Following Smith (1991), leakages can be taken into account using the following approach, illustrated in Eqs. (11)–(13) where: **m** is to represent the value of imports, **a**, the value of government production, and **v** is to equal the value of withdrawals from inventories; $\mathbf{x}_d$ is to equal domestic exports, and $\mathbf{x}_r$, re-exports. Final demand can be re-defined as:

$$\mathbf{e}^* = \mathrm{PE} + \mathrm{FCF} + \mathrm{VPCA} + \mathrm{GGCE},$$

where PE is the value of personal expenditures; FCF, the value of fixed capital formation in business and in government; VPCA, the value of inventory additions and GGCE, the value of gross government current expenditures on goods and services (Smith, 1991).

Assuming that leakages are in fixed proportion[2] to domestic commodity demand, leakage coefficients can be defined as following:

$$\mathbf{m} = \hat{\mu}(\mathbf{B}\,\mathbf{g} + \mathbf{e}^* + \mathbf{x}_r) \tag{11^3}$$

$$\mathbf{v} = \hat{\beta}(\mathbf{Bg} + \mathbf{e}^* + \mathbf{x}_d) \tag{12^4}$$

$$\mathbf{a} = \hat{\alpha}(\mathbf{Bg} + \mathbf{e}^* + \mathbf{x}_d) \tag{13}$$

where:

$\hat{\mu}$ = diagonal matrix of coefficients which correspond to the ratio between import and used commodity;

$\hat{\beta}$ = diagonal matrix of coefficients which correspond to the ratio between inventory withdrawal and used commodity;

$\hat{\alpha}$ = diagonal matrix of coefficients which correspond to the ratio between government production and used commodity.

Eq. (11) determines each import as a proportion of the sum of commodities required by intra- and inter-industry flows, final demand, and re-exports. Similarly, Eqs. (12) and (13) define each inventory withdrawal and government production as a proportion of the sum of commodities required by intra- and inter-industry flows, final demand, and exports.

Integrating these leakages into Eq. (8) gives:

$$\mathbf{g} = \mathbf{D}\big[\mathbf{Bg} + \mathbf{e}^* + \mathbf{x}_d + \mathbf{x}_r - \hat{\mu}(\mathbf{Bg} + \mathbf{e}^* + \mathbf{x}_r) - \hat{\beta}(\mathbf{Bg} + \mathbf{e}^* + \mathbf{x}_d) - \hat{\alpha}(\mathbf{Bg} + \mathbf{e}^* + \mathbf{x}_d)\big] \tag{14}$$

$$\mathbf{g} = \Big[\mathbf{D}\Big(\mathbf{I} - \hat{\mu} - \hat{\beta} - \hat{\alpha}\Big)\mathbf{Bg}\Big] + \mathbf{D}\Big[\Big(\mathbf{I} - \hat{\mu} - \hat{\beta} - \hat{\alpha}\Big)\mathbf{e}^* + (\mathbf{I} - \hat{\mu})\mathbf{x}_d + \Big(\mathbf{I} - \hat{\beta} - \hat{\alpha}\Big)\mathbf{x}_d\Big] \tag{15}$$

$$\mathbf{g} - \Big[\mathbf{D}\Big(\mathbf{I} - \hat{\mu} - \hat{\beta} - \hat{\alpha}\Big)\mathbf{Bg}\Big] = \mathbf{D}\Big[\Big(\mathbf{I} - \hat{\mu} - \hat{\beta} - \hat{\alpha}\Big)\mathbf{e}^* + (\mathbf{I} - \hat{\mu})\mathbf{x}_d + \Big(\mathbf{I} - \hat{\beta} - \hat{\alpha}\Big)\mathbf{x}_d\Big] \tag{16}$$

$$\Big[\mathbf{I} - \mathbf{D}\Big(\mathbf{I} - \hat{\mu} - \hat{\beta} - \hat{\alpha}\Big)\mathbf{B}\Big]\mathbf{g} = \mathbf{D}\Big[\Big(\mathbf{I} - \hat{\mu} - \hat{\beta} - \hat{\alpha}\Big)\mathbf{e}^* + (\mathbf{I} - \hat{\mu})\mathbf{x}_d + \Big(\mathbf{I} - \hat{\beta} - \hat{\alpha}\Big)\mathbf{x}_d\Big] \tag{17}$$

$$\mathbf{g} = \Big[\mathbf{I} - \mathbf{D}\Big(\mathbf{I} - \hat{\mu} - \hat{\beta} - \hat{\alpha}\Big)\mathbf{B}\Big]^{-1}\mathbf{D}\Big[\Big(\mathbf{I} - \hat{\mu} - \hat{\beta} - \hat{\alpha}\Big)\mathbf{e}^* + (\mathbf{I} - \hat{\mu})\mathbf{x}_d + \Big(\mathbf{I} - \hat{\beta} - \hat{\alpha}\Big)\mathbf{x}_r\Big] \tag{18}$$

The expression used to assess the economic impact on industrial output as a result of a change in final demand commodities is $[\mathbf{I}-\mathbf{D}(\mathbf{I}-\hat{\mu}-\hat{\beta}-\hat{\alpha})\mathbf{B}]^{-1}\ \mathbf{D}$ whereas $[\mathbf{I}-\mathbf{D}(\mathbf{I}-\hat{\mu}-\hat{\beta}-\hat{\alpha})\mathbf{B}]^{-1}$ represents the economic impact on industrial output as a result of a change in industrial output. This last bracketed quantity

[2] Assuming leakages in fixed proportions is the standard assumption when using the Canada Input–Output model. Further information on this can be found in Lal (1982).

[3] $\mathbf{x}_r$ is used here because re-export means that there is import beforehand.

[4] $\mathbf{x}_d$ is used here and in Eq. (13) because export means that there is national production beforehand.

corresponds to the *industry-by-industry total requirements* matrix corrected for economic leakages. Each element of this matrix determines the dollar's worth of industry i's output required to deliver one dollar's worth of industry *j*'s output to final demand, taking into account leakages such as imports, inventory withdrawals, and government production.

3. Input data

3.1. Economic data

Economic data were acquired from the I–O tables computed by Statistics Canada. The model was developed from the published data for the year 1999 (Statistics Canada, 2000, 2001, 2005). The industries and commodities in the 1999 I–O tables are aggregated at the North American Industry Classification (NAICS) medium level. The I–O model at this level of aggregation consisted of 111 commodities, which include 103 intermediate goods and 8 primary inputs, and 62 industries. Values are given in Canadian 1999 dollars.

The use matrix **U**, the total industrial output g, the make matrix **V** and the total commodity demand **q** are taken directly from the 1999 I–O tables. Data for the total commodity demand **q** are made equivalent to those of the total commodity supply **q'** in order to avoid mistakes when adding missing or incomplete data because of confidentiality.[5]

Leakage coefficients, which are assumed to be in a fixed proportion of commodity used, are derived from the final demand matrix.[6] GDP coefficients are derived from the GDP elements at basic prices. The basic price value is measured by the costs of labor (wages and salaries, supplementary labor income), capital inputs (mixed income and operating surplus), plus indirect taxes on factors of production less subsidies on production (Statistics Canada, 2001). This valuation divided by the total industrial output generates the GDP coefficients.

Employment coefficients are derived from the 1999 total national employment table. Total employment coefficients are computed by dividing all employments, taking into account paid workers, self-employed workers with paid help and self-employed workers without paid help, by total industrial output.

3.2. GHG emissions data

GHG emissions data and GHG direct plus indirect intensity 1999 coefficients are acquired from Statistics Canada (2000, 2001) and Environment Canada (2004). CO_2 equivalent emissions are estimated by using global warming potentials for methane and nitrous oxide whose values are set as 21 and 310 respectively (Houghton et al., 1996). Hence, the different types of GHG emissions (c = 1 to z) are compiled into only one unit, that is CO_2 equivalent.

GHG emissions data are available for 118 industries. This is a more disaggregated data set than the 62 industries found in the economic data. For this reason, the emission data have to be aggregated to fit into the same NAICS (North American Industry Trade Classification System[7]) medium level aggregation. For instance, the "Paper manufacturing" industry from the 62 industries-classification includes the "Pulp, paper and paperboard mills" industry and the "Converted paper products manufacturing" industry from the 118 industries-classification. Therefore, these two CO_2 equivalent GHG emissions are added together so as to obtain the same aggregation level as the economic data. GHG direct intensity coefficients are obtained by dividing each (aggregated) industry's GHG emissions by its (aggregated) industrial output. These 62 coefficients are expressed in tonnes of CO_2 equivalents per thousand 1999 dollars.

GHG direct plus indirect intensity coefficients are available for 118 industrial sectors. Hence, they also need to be aggregated in order to fit into the NAICS medium level aggregation of the economic data. However, this aggregation is weighted according to the importance of each industry. Keeping the same example as above, knowing that the "Pulp, paper and paperboard mills" industry accounts for 96.7% of the total emissions of the " Paper Manufacturing Industry" in the NAICS aggregation and that the "Converted paper products manufacturing" industry accounts for the remaining 3.3%, the direct plus indirect intensity GHG coefficient for this industry was weighted accordingly.[8] Table 2 shows GHG emissions, GHG direct intensity (DGHGI) coefficients as well as GHG direct plus indirect (DIGHGI) coefficients for 1999.

4. Policy scenarios

If Canada is to meet its Kyoto commitment by reducing industrial output then one of the important policy decisions is the allocation of GHG reductions to the industrial sectors. Three policy scenarios using different allocation rules that result in a different distribution of GHG reductions are analyzed. The allocation mechanism used is either the direct GHG emissions by industry or the direct plus indirect GHG emissions. Direct plus indirect GHG emissions include the GHG emissions from the initial industrial sector and all of the backward linkages to that sector. For example, the direct plus indirect GHG emissions from the agriculture sector would include, among others, the GHG emissions from the fertilizer sector for the fertilizer that is used by the agricultural sector.

[5] A few confidential data are not mentioned in the Tables (Statistics Canada, personal communication, 2005).

[6] However, it is important to underline that the total commodity demand **q** and **Bg** - the values of each element of the use matrix **U** — for primary products of copper and copper alloys as well as for primary products of nickel and nickel alloys are not given in the 1999 I–O tables. They were then calculated by adding each element of the total commodity demand **q** and each element of the Use matrix **U** for these products. Furthermore, the total commodity demand **q** for non-competing imports and unallocated imports and exports were evaluated, without loss of generality, at 1 million dollars instead of 0 in order to avoid any problem when calculating inverse matrices.

[7] This system has been developed jointly by the US, Canada and Mexico to provide new comparability in statistics about business activity across America.

[8] The coefficient is equal to $(0.967 \times 1.35) + (0.033 \times 0.75) = 1.33$ t of CO_2 equivalent per thousand 1999 dollars.

Table 2 – GHG emissions, DGHGI and DIGHGI coefficients for the 62 Canadian industries

No.	Industrial sector	GHG emiss. (kt CO_2 eq.)	DGHGI coeff. (tCO_2 eq./1000 99$)	DIGHGI coeff (tCO_2 eq./1000 99$)
1	Crop and animal production	63455	1.80	3.17
2	Forestry and logging	4060	0.30	0.81
3	Fishing, hunting and trapping	1393	0.70	1.14
4	Support activities for mining and oil and gas extraction	565	0.43	0.70
5	Oil and gas extraction	90752	2.48	2.82
6	Mining (expect oil and gas)	8040	0.56	1.27
7	Support activities for agriculture and forestry	1852	0.29	0.78
8	Electric power generation, transmission and distribution	115769	4.00	4.28
9	Natural gas distribution, water and other systems	4666	1.19	1.34
10	Construction	7451	0.07	0.72
11	Food manufacturing	3723	0.07	1.29
12	Beverage and tobacco product manufacturing	718	0.06	0.58
13	Textile and textile product	571	0.09	0.70
14	Clothing manufacturing	153	0.02	0.40
15	Leather and allied product manufacturing	43	0.00	0.51
16	Wood product manufacturing	2348	0.08	0.60
17	Paper manufacturing	11868	0.36	1.33
18	Printing and related support activities	248	0.02	0.56
19	Petroleum and coal products manufacturing	23168	1.03	3.41
20	Chemical manufacturing	23517	0.66	3.50
21	Plastics and rubber products manufacturing	911	0.05	0.72
22	Non-metallic mineral product manufacturing	16245	1.75	2.93
23	Primary metal manufacturing	25124	0.70	1.68
24	Fabricated metal products manufacturing	1411	0.06	0.72
25	Machinery manufacturing	576	0.02	0.48
26	Computer and electronic product manufacturing	142	0.00	0.28
27	Electrical equipment, appliance and component manufacturing	292	0.03	0.62
28	Transportation equipment manufacturing	2224	0.02	0.55
29	Furniture and related product manufacturing	285	0.03	0.44
30	Miscellaneous manufacturing	235	0.04	0.58
31	Wholesale trade	14020	0.18	0.44
32	Retail trade	10398	0.14	0.39
33	Truck transportation	19922	0.84	1.49
34	Transit and ground passenger transportation	2699	0.55	0.93
35	Pipeline transportation	17741	3.17	3.36
36	Air,rail,water and scenic and sightseeing transportation and support	26376	0.81	1.68
37	Postal service and couriers and messengers	1281	0.15	0.49
38	Warehousing and storage	232	0.12	0.36
39	Motion picture and sound recording industries	785	0.12	0.54
40	Broadcasting and telecommunications	792	0.03	0.18
41	Publishing industries, information services and data processing service	141	0.01	0.31
42	Finance, insurance, real estate and renting and leasing	12682	0.05	0.34
43	Professional, scientific and technical services	2265	0.04	0.24
44	Administrative and support services	1734	0.07	0.26
45	Waste management and remediation services	1023	0.38	0.68
46	Education institutions	745	0.28	0.48
47	Health care and social assistance	1249	0.04	0.23
48	Arts, entertainment and recreation	349	0.03	0.32
49	Accommodation and food services	2465	0.06	0.56
50	Repair and maintenance	1870	0.20	0.46
51	Grant-making, civic, and professional and similar organizations	33	0.02	0.14
52	Personal and laundry services and private households	696	0.07	0.31
53	Operating, office, cafeteria and laboratory supplies	13	0.00	0.63
54	Travel, entertainment, advertising and promotion	5877	0.15	1.17
55	Transportation margins	0	0.00	1.37
56	Non-profit institutions excluding education	1704	0.11	0.46
57	Education institutions	329	0.17	0.40
58	Hospitals and residential care facilities	927	0.03	0.21
59	Education	4263	0.08	0.25
60	Other municipal government services	2920	0.09	0.36
61	Other provincial and territorial government services	1713	0.03	0.26
62	Other federal government services and defense services	2759	0.07	0.28
	Total GHG emissions	551808		

Source: personal computations from Statistics Canada (2000, 2001 and 2005).

Table 3 – Summary of the three main steps to assess the change in industrial output as a result of the Kyoto commitment

Steps		Scenario 1	Scenarios 2 and 3
1)	Data collection	Get the following estimated data: GHG_{1999}, DGHGI coeff. And DIGHGI coeff.	
2)	Change in GHG emissions	$\Delta GHG = GHG_{Kyoto\ level} - GHG_{1999}$	
3)	Change in industrial output	$\Delta g = \Delta GHG/DGHGI$ coeff.	$\Delta g = \Delta GHG/DIGHGI$ coeff.

A three step process, illustrated in Table 3, is used to allocate the GHG emission reductions for the various scenarios. The first step starts with the computed direct GHG index (DGHGI) and direct plus indirect GHG index (DIGHGI) explained in Section 3.2 and illustrated in Table 2. The second step estimates the change in GHG emissions that would be required to satisfy the Kyoto commitment. This is determined by taking 94% of the 1990 GHG emissions for each industrial sector and subtracting the 1999 GHG emissions for each industrial sector. The final step estimates the change in industrial output required to meet this GHG emission reduction. To estimate this value, the change in GHG emissions (step 2) for each industrial sector is divided by the direct GHG emission coefficient in scenario 1 and by the direct plus indirect GHG emission coefficient in scenarios 2 and 3.

As can be seen in Table 3, in the first policy scenario, the change in industrial output for each industrial sector is a function of the GHG emissions in 1999, the GHG emissions in 1990, and the industrial output in 1999. It allocates the emission reductions based on a 6% reduction of the 1990 emission level for each sector, which means that each sector would need to reduce its emissions by more or less than 6% depending how their emission varied between 1990 and 1999.

The second policy scenario takes into account the backward linkages inside the Canadian economy. Consequently, the direct plus indirect GHG intensity coefficients are used in the GHG emissions target computation. In this case, the decrease in industrial output is a function of the reduction in GHG emissions and the direct plus indirect emission coefficient for the sector.

The third scenario allocates the GHG emission reductions, required to meet Canada's Kyoto commitment, to the 12 top emitting sectors. These industrial sectors – identified in Table 4 – have the 12 highest direct plus indirect intensity coefficients[9] and altogether, produce 79% of the total Canadian industrial GHG emissions. In other words, it is estimated that pollution abatement should be targeted towards these 12 sectors as they are the most GHG intensive and account for most of the GHG emissions; targeting less than 12 sectors would be unrealistic as it would impose too high a burden on these industries and a larger target would not be too different from the previous scenario. This policy scenario allocates an equal percentage of GHG emissions reduction amongst the 12 top emitting industries, each of which would have been required to reduce its 1999 GHG emissions by 22% (as their emissions generally increased between 1990 and 1999), should the KP have been reached in 1999.

The cost of these different policies is examined in terms of decreases in industrial output, GDP, and total employment and compared so as to determine the least cost policy to satisfy Canada's Kyoto commitment.

The economic cost of cutting GHG emissions by reducing total industrial output is computed by multiplying the inverse matrix $[\mathbf{I}-\mathbf{D}\ (\mathbf{I}-\hat{\mu}-\hat{\beta}-\hat{\alpha})\mathbf{B}]^{-1}$, deducted from Eq. (18), by the decrease in industrial output ($\Delta\mathbf{g}$) required by the three policy scenarios. As mentioned earlier, the inverse matrix corresponds to the *industry-by-industry* requirements matrix, which is modified to take into account economic leakages as a result of imports ($\hat{\mu}$), inventory withdrawals ($\hat{\beta}$) and government production ($\hat{\alpha}$). This approach estimates how each Canadian industrial sector is affected by a reduction in industrial output if the Canadian Kyoto commitment was reached in 1999.

5. Results

The reduction in industrial output for each scenario is run as a change in final demand for the industrial output for the Canadian economy. This initial change in final demand is the direct effect for each of the scenarios. It is then pre-multiplied by the impact matrix to estimate the direct plus indirect effect on the economy. As can be seen below, the allocation or distribution of this initial effect to the industrial sectors has a major impact on the cost of the policy as well as on employment and GHG reduction.

Table 5 displays the impacts of the various scenarios on industrial output, GDP, employment and GHG emissions, under the hypotheses of meeting the Kyoto target i) instantaneously (that is, without any dynamics involved and without

Table 4 – The top 12 GHG emitting industrial sectors on the basis of GHG direct plus indirect intensity coefficients

No.	Industrial sector	DIGHGI coeff. (CO_2 eq t./1000$)	1999 GHG em. (kt)
1	Electric power generation	4.28	115769
2	Chemical manufacturing	3.50	23517
3	Petroleum and coal products manufacturing	3.41	23168
4	Pipeline transportation	3.36	17741
5	Crop and animal production	3.17	63455
6	Non-metallic mineral product manufacturing	2.93	16245
7	Oil and gas extraction	2.82	90752
8	Air, rail, water & scenic. and sightseeing transport & support	1.68	26376
9	Primary metal manufacturing	1.68	25124
10	Truck transportation	1.49	19922
11	Natural gas distribution, water and other systems	1.34	4666
12	Paper manufacturing	1.33	11868
	Total	–	438603

[9] Following these rules, the *Transportation margins* industrial sector, which has a GHG direct plus indirect coefficient of 1.37 but does not produce any GHG emissions by definition, is not considered inside the list of the 12 top emitting sectors.

Table 5 – Economic and environmental impacts of the three policy scenarios

	Scenario 1		Scenario 2		Scenario 3	
	Direct effect	Direct+indirect effect	Direct effect	Direct+indirect effect	Direct effect	Direct+indirect effect
Reduction of industrial output (%)	−13.7	−22.9	−4.6	−7.3	−1.9	−3.1
Reduction of GDP (%)	−15.4	−24.0	−5.6	−8.1	−2.0	−3.1
Reduction of employment (%)	−20.0	−28.5	−5.9	−8.3	−1.1	−2.1
Resulting GHG emissions reduction (kt of CO_2 eq.)	−96680	−168523	−80868	−96680	−66928	−96680

allowing for technological changes) and ii) by reducing industrial production only (that is, without taking advantage of the flexibility mechanisms), which prevents cheaper or additional emissions reduction. As mentioned earlier, this brings about upper cost estimates.

5.1. *Policy scenario 1*

In the first policy scenario, the change in industrial output is estimated using the direct GHG emission coefficient for each industrial sector. Each sector is compelled to decrease its GHG emissions by 6% below 1990 levels. Thus, the burden of GHG emissions is distributed uniformly, in a relative sense. The initial reduction in final demand using this approach is estimated at 13.7%, as reported in Table 5. This is spread across all 62 industrial sectors. The impact of this direct effect is a GDP loss of 15.4% and a reduction in employment of 20%.

The direct plus indirect effect of this initial decrease in industrial output, obtained by running the ecological–economic I–O model, leads to a 22.9% reduction in industrial output, a 24% reduction in GDP, and a 28.5% reduction in employment.

These impacts are very high because the initial distribution is based solely on the direct GHG coefficients, but the direct plus indirect effect – that is, the real impact on the economy – supplies a greater GHG emission reduction than is necessary. Hence, using direct GHG emission coefficient to uniformly allocate industrial output reduction is obviously not an adequate policy as it underestimates the final GHG reduction and places an unbearable burden on the economy.

5.2. *Policy scenario 2*

In this scenario, the initial decrease in industrial output is based on the direct plus indirect GHG coefficients for each industrial sector, bearing a 6% reduction from their 1990 GHG emission levels. Therefore, in relative terms each industrial sector has an equal reduction in GHG emissions with respect to 1990; which means that those sectors for which emissions increased between 1990 and 1999 have to bear a larger burden for going back to their Kyoto target.

As illustrated in Table 5, the direct effect of this scenario shows a much smaller impact than in the first one. Industrial output is reduced by 4.6% instead of 13.7%, GDP goes down by 5.6% instead of 15.4% and the loss of jobs reaches 5.9% instead of 20% in the first scenario. However, the resulting GHG emissions are higher than the Kyoto target. Indeed, emissions are reduced by 80,868 kt instead of the 96,680 kt required by the Kyoto Protocol. This is due to the fact that the Kyoto target is based on the total industrial impact that is, the direct plus indirect effect.

The real effect on the economy in terms of output, GDP and employment is as such. Industrial output is reduced by 7.3% and GDP by 8.1%. The impact is thus three times lower than that of the first scenario where output and GDP went down respectively by 22.9% and 24%. Employment would be reduced by 8.3%, compared to 28.5% in the first scenario.

In summary, taking into account backward linkages in the Canadian economy, that is, using the direct plus indirect GHG emission coefficient when deciding to allocate industrial output restriction as a means to satisfy Canada's Kyoto target greatly reduces the cost of the policy.[10] The burden on the economy is divided by a factor of 3 compared to the first scenario. However, a 5.6% GDP reduction is not trivial; this is the reason why a third scenario is suggested.

5.3. *Policy scenario 3*

The third policy scenario allocates the Kyoto target to the twelve top GHG emitting industries based on their direct plus indirect GHG emission coefficient as illustrated earlier in Table 4.

The direct effect in Table 5 shows a much smaller impact than the two previous scenarios. As an illustration, the loss in GDP (2%) is about a third of that of scenario 2 (5.6%) and close to eight times less than in scenario 1 (15.4%). The difference between the three scenarios is even larger for job losses: 1.1% compared to 20% and 5.9% in the first two scenarios. Hence, the total impact on the economy is far less costly than the two previous scenarios. However, the resulting GHG emissions are above the Kyoto target for the same reason as in scenario 2.

In the direct plus indirect effect, the resulting GHG emissions equal the Kyoto target and consequently, the impact on the economy is somewhat larger, but it stays very low compared to the same effects in the other scenarios. As a matter of fact, industrial output is only reduced by 3.1% compared to 22.9% and 7.3%, respectively in scenarios 1 and 2. Job losses are respectively 13 and 4 times lower in scenario 3 (2.1%) than in the two first scenarios. And GDP

[10] Note that the three industrial sectors most affected by this policy are: the "Wholesale trade" industry, the "Oil and gas extraction" industry, and the "Professional, scientific and technical services" industry. These sectors account for 13.7%, 9.8%, and 7.4% of the total direct plus indirect effect respectively.

goes down by 3.1% compared to 24% in scenario 1 and 8.1% in scenario 2.[11]

Reaching the KP by decreasing industrial output in the top 12 polluting industries and using the direct plus indirect GHG emission coefficients to allocate the uniform reduction is therefore the cheapest of the three alternatives.

6. Conclusions and caveats

Based on the restrictive hypotheses that (a) the only way for Canada to meet its Kyoto commitment is to decrease its industrial output, (b) industries are not allowed to use flexibility mechanisms, and (c) the Kyoto commitment is satisfied in one year through a reduction of industrial output, the results of the analysis indicate that a reduction in GHG emissions obtained by reducing industrial output causes negative impacts on the Canadian economy. These impacts vary greatly by scenario. The differences in the cost of compliance are the result of the initial allocation of the reduction in industrial output.

If government decision-makers use the direct GHG emission coefficients to determine each industrial sector reduction in output, as in scenario 1, they will over-supply the required GHG emission reductions for Canada's Kyoto commitment. This is because it does not take into account the backward linkages in the economy, when making the initial allocation of industrial output reductions. This allocation would be a high cost policy choice for Canada as a means of respecting its commitment.

The decision rules used in policy scenarios 2 and 3 to allocate the industrial output reductions take into account the backward linkages in the economy and thus provide a better allocation mechanism. Scenario 2 assigns the reductions in each industry's output based on the difference between 94% of an industry's 1990 GHG emissions and its 1999 GHG emissions. Using this approach to allocate the reduction in industrial output results in a substantial drop in GDP (8.1%).

Policy scenario 3 allocates the reduction in industrial output to the 12 industrial sectors that have the largest direct plus indirect GHG emission coefficients. Of the three policy scenarios, this allocation provides the least cost alternative to satisfying Canada's Kyoto commitment. The decrease in GDP in this scenario is 3.1%.

The results that are obtained from the policy analysis are as expected. A priori, one would expect that industrial sectors with larger direct plus indirect GHG emission coefficients would be able to supply GHG reductions with smaller decreases in industrial output. A few conclusions can be drawn.

[11] Note that the largest impacts in terms of GDP occur in two industrial sectors: The "Petroleum and coal products manufacturing" industry (34.4%) and the "Oil and gas extraction" industry (31.9%). Moreover, the twelve top GHG emitting industries are the most affected in terms of reduced GDP (from 25.8% to 34.4%). As far as the other impacts are concerned, the biggest reduction in industrial output occurs in the "Oil and gas extraction" industry when the direct plus indirect effects are accounted for and the largest reductions in total employment occurs in the twelve top GHG emitting industries, as expected, with a major impact on the two industries whose GDP impact is the largest.

First, this analysis shows that it is crucial to consider linkages among industrial sectors in analyzing the economic impact of GHG emissions. Not doing so would overestimate the negative impacts; indeed, GDP losses in scenario 1 are three times larger than those in scenario 2.

Second, the analysis also shows that a comparable policy option – uniform output reduction – has a dramatically different result if all industries are constrained versus if only the largest polluting industries have to limit emissions by decreasing industrial output. The former situation more than doubles GDP losses compared to the latter one (8.1% versus 3.1%). This suggests that industries with the largest GHG emissions should be required to bear a larger burden (in relative terms) of the global effort.

Third, the purpose of this study was to use hypotheses that do *not* contribute to a cost-efficient method for respecting the KP so that upper-bound costs could be found. Indeed, no dynamics are involved, unlike in other studies (e.g., Nordhaus and Yang, 1996), so firms cannot develop and adopt technologies that reduce GHG at lower cost. No flexibility mechanisms – known to reduce the adverse economic impacts of GHG abatement – are considered, contrary to many studies (e.g., Pan, 2005). Also, abatement is not dependent on marginal abatement costs, since all industries in scenarios 1 and 2 and all top 12 emitting industries in scenario 3 uniformly abate to reach the Kyoto target, which is not economically efficient in terms of global cost analysis. Moreover, had trading emission permits or other market-based instruments been allowed, the cost of meeting Kyoto's target would have been reduced (e.g., Tietenberg, 1990). Targeting would also be a more cost effective way to achieve Canada's Kyoto commitment as previously shown, among others, in Carpentier et al. (1998). Hence, the resulting GDP reductions incurred by Canada, for fulfilling its Kyoto requirement, should indeed be considered as upper-bound costs in all scenarios. Therefore, the GDP impact of scenario 3 (−3.1%) should also be qualified as an upper-bound impact.

Finally, comparing these results with those of the Energy Modeling Forum (EMF-16) analysis, which gathered various models' results (Weyant and Hill, 1999), it is estimated that if Canada, Australia, and New Zealand fulfilled their Kyoto commitment with decreases in industrial output, then their GDP would decrease by 0.6 to 2.02% in 2010 – with an average of 1.53 – if no trading is allowed and by 0.23 to 1.14% – with an average of 0.65 – with trading between Annex I countries (IPPC, 2001). Hence, using the same proportion between GDP reduction with and without emission trading, it would mean that – on average – reducing industrial output in Canada's top 12 emitting industries while allowing carbon permit trading might reduce the 1999 GDP by 1.31%. If such a policy of output restriction is not the preferred option for developed nations, this number – far less than half of the average annual real Canadian GDP growth for the period 1966–2005[12] – seems to contradict the often heard statement that restraining industrial output for tackling climate change would bring about an unbearable economic burden and a possible economic collapse.

[12] The average 1966–2005 growth rate is 3.4% and the lowest growth rate of the past 10 years is 1.77% in 2001.

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