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Greenhouse Gas Intensity in Canada: A Look at Historical Trends

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L'un des principaux éléments sur lequel s'appuie la récente politique gouvernementale en matière de gaz à effets de serre (GES) est la réduction de l'intensité des émissions de GES. Dans cet article, nous examinons ce projet à la lumière des tendances observées entre 1990 et 2002, et en décomposant les variations d'intensité, grâce à un indice chaîne de Divisia, en effets de composition et en effets techniques. Nos résultats montrent que cette politique obligerait l'industrie à changer ses façons de faire, puisqu'elle devrait effectuer des réductions d'intensité comme jamais auparavant. Notre analyse suggère également qu'il serait difficile d'atteindre ces objectifs uniquement grâce à des progrès technologiques.

Mots clés : intensité des émissions de gaz à effets de serre, indice chaîne de Divisia, protocole de Kyoto

A central pillar of the Canadian government's recent greenhouse gas plan is to decrease the greenhouse gas intensity of production. We consider the proposal in light of historical trends between 1990 and 2002 by decomposing the change in emission intensities into composition and technique effects using a divisia index approach. Our results demonstrate that the proposed policy would push businesses into reductions in emission intensities that they have not previously accomplished. It would not be business as usual. Our analysis also suggests that achieving these targets by technological improvements alone may be quite difficult.

Keywords: greenhouse gas intensity, divisia index, Kyoto Protocol

Introduction

In its *Regulatory Framework for Air Emissions*, the Government of Canada (2007) has laid out a plan to reduce greenhouse gas (GHG) emissions in a number of pollution-intensive industrial sectors, in addition to reducing transportation and residential emissions. It has chosen to target reductions in *GHG emission intensity* rather than impose an explicit limit or cap on total emissions. Specifically, the legislation would require targeted facilities to reduce their GHG emissions per unit of production by 18 percent in 2010 from their 2006 levels. A further 2 percent cut would occur in each subsequent year. The policy explicitly focuses on improving the techniques of production. Though firms' emissions are permitted to grow as output grows, the intention of the policy is that efficiency gains will eventually outweigh output growth and, thus, decrease total emissions.

An important question is whether the current proposal is feasible. This depends in part on whether it marks a significant change from historical trends. Herzog, Baumert, and Pershing (2006, 16) point out that a similar proposal in the United States to reduce their GHG intensities by 18 percent did not "represent a stringent policy with respect to historical trends in either total emissions or emission intensities." Rather, that policy more or less enforced historical trends and so did not constitute a break from business as usual. We ask whether the current Canadian proposal is any different. To this end we document the changes in emission intensity that have taken place in Canada using publicly available data from 1990 to 2002. We then compare the historical performance relative to targeted performance. Our objective is not to assess directly the government's objective or its regulatory approach. Rather, we wish to evaluate the proposed reductions in intensity to see how significant they are in terms of achieving real reductions from business as usual. Since the proposal focuses on technological gains, we also want to analyze whether the targeted sectors are likely capable of achieving these targets with improvements in techniques alone.

To answer these questions we first decompose trends in GHG intensities into those that can be attributed to changing industry structure (a composition effect) and those that can be attributed to changing techniques of production (a technique effect). The proposed policy, however, gives credit only for emission reductions that arise from changes in the techniques of production. These technological changes entail investments in energy efficiency, investments in carbon capture, fuel switching, and changes in the way in which firms produce their output. The proposal is explicit in that it does not give carbon credits as a result of reductions in output driven by economic events or for moving production off shore. Hence changes in the composition of industry structure, though such changes may contribute to diminishing emission intensity overall, cannot be used by regulated facilities to meet their own emission intensity targets. Since a primary driver of GHG emissions is combustion of fossil fuels, we also look at the historical trends in energy intensity. We then compare the historical record against the proposed targets to assess whether the proposal constitutes real change.

As a point of comparison, we also look at the experience of the United Kingdom over the same period for a selection of comparable industrial sectors.[1] The comparison is informative as both Canada and the UK have experienced very similar overall real economic growth, and yet GHG intensity for the target industries in Canada fell by only 8 percent between 1990 and 2002 compared with about 18 percent in the UK. To the extent that the UK has taken its Kyoto commitments more seriously than Canada, we look briefly at how the UK may have managed this.

Our results suggest that the proposed policy is not business as usual. It would push Canadian businesses into emission reductions at a pace that they have not previously accomplished. In fact, the data show that both Canadian and UK businesses have had only limited success in reducing GHG emissions through improvements in their production processes alone. Energy intensity in the targeted sectors has worsened over time. Most of the observed decreases in GHG intensity, rather, can be attributed to changing the composition of production. In the UK, reductions in emission intensities also appear to be driven by fuel switching from coal to natural gas. The ability to reduce GHG emissions by fuel switching is more limited in Canada as we do not rely heavily on coal as an energy source. We leave open the question whether the proposed legislation provides sufficient incentives for targeted facilities to initiate the required technological improvements to achieve significant reductions in emissions.

The remainder of the paper is structured as follows: We provide some background on the proposed Canadian policy and compare Canada's performance relative to other Annex 1 countries, discuss the divisia index decomposition approach and data sources, present results for Canada and the UK, analyze some simple policy scenarios to assess how close the proposal might come to achieving Kyoto targets, and offer concluding remarks.

Background

Canada, when it ratified the Kyoto Protocol in 2002, committed to reduce its total GHG emissions by 6 percent over the period 2008 to 2012 from 1990 levels. We are far from achieving that target. Table 1 compares Canada's performance in reducing GHG overall and in our industrial sectors to that of other Annex 1 countries. Emission data cover 1990 to 2003 and come from the United Nations Framework Convention on Climate Change (UNFCC). As of 2003, total GHG emissions from all sources in Canada had risen 25 percent above 1990 levels (UNFCC 1990–2003). Despite the fact that few countries have achieved significant reductions in GHG emissions, Canada's lack of progress has been a source of disappointment to some.

We can also compare Canada to the other countries in terms of emissions per unit of gross domestic product (GDP). Output is measured in constant (2000) $US and comes from the World Development Indicators (World Bank 2009). Canada's emission intensity of 0.97 kilotonnes per million dollars of output is almost twice the average for the group, but it did fall by 17 percent over the period.

The same emissions pattern emerges in the industrial sectors, which include only manufacturing, energy extraction, and energy production. GHG emissions include by-product or fugitive emissions from industrial processes and emissions from fuels combusted by the fuel extraction and energy-producing industries. The data do not include changes in emissions from land use, land-use changes, and forestry. Between 1990 and 2003, GHG emissions from the industry and energy sectors in Canada rose 31 percent, faster than emissions in the economy as a whole. GHG intensity was 1.25 kt per million dollars of output in 1990, which is higher than the average for the group but certainly not the highest in the sample. By 2003, industrial GHG intensities had fallen by only 4 percent in Canada. This rate of decrease in intensities is about average for the sample countries with about half the countries reducing emission intensities faster than Canada. Note that for virtually all countries, the decrease in emission intensities in the industrial sector was much smaller than in the economy as a whole, suggesting that reductions in industrial emissions may be harder to achieve than reductions in other areas.

The Canadian government, in response to the lack of progress in reducing GHG emissions, has proposed a new policy laid out in its *Regulatory Framework for Air Emissions* (Government of Canada 2007). One of the main elements is to target a select number of GHG-intensive industries. The policy target is an 18 percent reduction in GHG intensities (emissions per unit of output) from 2006 levels by 2010 with a further 2 percent cut in each subsequent year. The industrial regulations will cover facilities in the following sectors, which account for about half of Canada's GHG emissions from industrial sources (Government of Canada 2007, 7):

- electricity generation produced by combustion;
- oil and gas (including upstream oil and gas, downstream petroleum, oil sands, and natural gas pipelines);
- forest products (including pulp and paper and wood products);

TABLE 1
Greenhouse Gas Emissions and Intensity for Selected Annex 1 Countries, 1990–2003

		GHG Emissions from All Sources[a]			*GHG Emissions from Industry*[b]		
	Kyoto Targeted Reductions[c] *2008–2012 (%)*	*Change in GHG Emissions 1990–2003 (%)*	*GHG Intensity*[d] *1990*	*Change in GHG Intensity 1990–2003 (%)*	*Change in Emissions from Industry 1990–2003 (%)*	*GHG Intensity*[d] *1990*	*Change in GHG Intensity 1990–2003 (%)*
Australia	8	26	1.16	–25	38	2.38	0
Austria	–8	18	0.46	–15	13	0.68	–18
Belgium	–8	–1	0.62	–26	–5	1.31	–17
Canada	**–6**	**25**	**0.97**	**–17**	**31**	**1.25**	**–4**
Denmark	–8	–7	0.46	–33	18	1.07	0
Finland	–8	–2	0.67	–27	50	1.23	9
France	–8	–2	0.41	–25	–3	0.63	–17
Germany	–8	–18	0.54	–36	–18	1.15	–19
Greece	–8	27	1.05	–19	23	2.94	–6
Iceland	10	11	0.4	–28	17	0.29	–17
Italy	–8	12	0.51	–7	10	0.87	2
Japan	–6	7	0.29	–12	10	0.45	15
Netherlands	–8	0	0.55	–28	12	1.17	–3
New Zealand	0	25	1.28	–21	30	1.05	–5
Norway	1	9	0.31	–32	59	0.23	11
Portugal	–8	43	0.72	4	23	1.19	0
Spain	–8	53	0.64	0	41	1.02	3
Sweden	–8	–7	0.28	–32	16	0.51	–22
United Kingdom	–8	–15	0.43	–40	–12	1.05	–20
United States	–7	16	0.69	–26	18	1.66	–12
TOTAL		**10**	**0.56**	**–22**	**12**	**2.38**	**–3**

Notes: GHG = greenhouse gas.
[a] Total GHG emissions include all sources except land use, land-use changes, and forestry.
[b] Industry GHG emissions are measured in kilotonnes of CO2 equivalent and include by-product or fugitive emissions of greenhouse gases from industrial processes and emissions from fuels combusted by the fuel extraction or energy-producing industries.
[c] The Kyoto target is for total GHG reductions based on 1990 levels.
[d] Emission intensities are measured in kilotonnes of CO2 equivalent per million dollars in constant 2000 $US.
Source: United Nations Framework Convention on Climate Change (1990–2003); GDP and industrial output data are from the World Bank (2009).

- smelting and refining (including aluminum, alumina, and base metal smelting);
- iron and steel;
- some mining; and
- cement, lime, and chemicals (including fertilizers).

As the firms to be regulated share many common characteristics, the aim is to encourage coordination and synergies between firms to make cost-effective reductions. If in-house reductions (such as energy efficiency measures, improved energy management systems, or investments in carbon capture and storage or other emission-reducing technologies) cannot be cost-effectively undertaken, then firms will have access to other credit avenues. They can contribute to a technology fund (at $15 per tonne of CO2 equivalent), engage in domestic emissions trading, create offsets, or trade emissions and buy credits under the Kyoto Protocol's Clean Development Mechanism. These options allow individual plants to raise their actual GHG intensity as long as offsets lead to an overall reduction in worldwide emissions.

The Government of Canada is not the only one to take an intensity approach. The United Kingdom, United States, and Argentina have also proposed regulations to limit emission intensities (see Herzog, Baumert, and Pershing 2006 for a review). The Bush plan called for an 18 percent reduction in GHG intensities from 2002 to 2012. Similarly, Alberta's *Climate Change and Emissions Management Amendment Act* compels companies that emit more than 100,000 tonnes of greenhouse gases a year to reduce their emissions intensity by 12 percent starting 1 July 2007 (Legislative Assembly of Alberta 2007). The targeted firms contribute about 70 percent of Alberta's industrial emissions. In fact, many of the features in the Alberta legislation have parallels in the federal proposal.

Implementing intensity targets presents some challenges and tradeoffs. The intensity approach is not equivalent to a cap-and-trade system or to emission taxes and may not be the most efficient regulatory approach. For instance, Helfand (1991) showed that intensity targets are not the least cost approach to regulating pollution. Firms facing intensity targets may tend to "dilute" emissions by raising production above the levels for cap-and-trade firms. This dilution forces regulators to impose stricter intensity targets than would arise under a cap-and-trade system alone, and so firms need to abate more to achieve the same target. On the other hand, Montero (2002) and Bruneau (2004) show that innovation in, and adoption of, new technologies may be stronger under intensity targets. The idea is that improved technologies lower the costs of complying with existing regulations, allowing firms to raise output without necessarily raising emissions. This output-promoting effect can be stronger under emission intensity targets than under, say, a cap-and-trade system. As Bruneau shows, improvements in technology can raise total emissions even as intensities fall. The challenge for governments choosing the intensity approach is to ensure that intensity targets fall quickly enough to limit total emissions over time.

Another challenge, recognized in the proposal and central to its implementation, is that firms will not be given credit for shutting down production if this is done for economic reasons or if they move production out of Canada (Government of Canada 2007, 10). Credits can be earned only through cleaner production. This restriction discourages leakage of emissions to non-Kyoto signatories and corrects a weakness inherent to emissions taxes and cap-and-trade systems.

Another challenge with the intensity approach, not fully laid out in the framework, is how to measure output: by value or by quantity? For instance, a fall in output prices, holding production constant, would raise emission intensities even though there are no changes in real activity and in actual emissions. On the flip side, rising prices would dilute emissions, making targets easier to meet. In single-output plants, price changes are easily accommodated by measuring output in volumetric terms (tonnes of steel, cubic metres of chemicals, etc.). However, as most plants produce multiple outputs, measuring real output requires aggregating production into a common dollar value. This requires plant-specific price deflators. Failure to account for relative price changes could allow firms to shift production to less emission-intensive product lines thereby reducing average intensity without altering actual production processes.

Decomposing Intensity Changes: Methodology and Data

Differences in GHG intensities and their decreases, as documented in Table 1, can be attributed to two primary effects (Cole and Elliott 2003; Cole, Elliott, and Shimamoto 2005; Copeland and Taylor 2003; Grossman and Krueger 1995). The first component is the *composition* of economic activity within the economy. Different activities use energy in differing intensities and emit GHG at different rates. For instance, GHG emissions per dollar of pesticide, fertilizer, and other agricultural chemical manufacturing are over 200 times more than that of household appliance manufacturing (Statistics Canada 1990–2002, Tables 153-0034 and 379-0017). Over time, the composition of production can shift due to exogenous demand factors or to changes in environmental policies. All things equal, stricter GHG regulations will tend to hurt GHG-intensive industries more and so shift productive resources to less GHG-intensive industries. This internal shift can be pushed further by the forces of comparative advantage in trade (for a discussion, see Cole and Elliott 2003; Copeland and Taylor 2003). The proposed regulatory framework recognizes this effect by allowing emissions to rise within expanding industries while denying credit to contracting industries.

The second component, and the focus of the proposed regulation, is the *technique* used in production. Technique is measured as the emission intensity of production after accounting for changes in composition. Enterprises can alter their techniques of production in two primary ways. First, they can focus on energy, since reductions in energy use contribute directly to reductions in GHG emissions. For example, plants can turn to more energy-efficient processes or invest in more energy-efficient capital. They can also switch their energy sources from high GHG fuels, like coal, to lower GHG fuels, like natural gas[2] or renewable energies. Electricity producers have the greatest scope for switching since one-third of the energy used in electricity production comes from coal (Natural Resources Canada 2006b). Second, plants can also alter production processes that directly contribute to GHGs or abate emissions.[3] For instance, Timilsina, Naini, and Walden (2006, 40) report that 14 percent of Alberta's total GHG emissions in 2003 came from fugitive emissions in the production, processing, transmission, storage, and delivery of oil and gas. For Canada as a whole in 2004, 73 percent of total GHG emissions in industry came from combustion of fossil fuels and another 9 percent from fugitive emissions (Natural Resources Canada 2006a). The remaining 18 percent of industrial GHG emissions came from processing.

How quickly firms alter techniques of production depends on the strength of the incentives facing plants and the ease with which they can alter behaviour, processes, and capital stocks. However, whether the proposed binding targets provide a strong enough incentive for firms to engage in process innovation is uncertain. The business response depends in part upon whether the proposed policy significantly strengthens current incentives to improve energy efficiency. If the proposal is stringent, then plants may want to innovate at a faster pace. If the proposal is weak, then plants can take a more business-as-usual approach.

To identify how much of the observed recent changes in emission intensity can be attributed to changes in techniques, we use the divisia index methodology described in Cole, Elliott, and Shimamoto (2005, 62-3) to decompose the changes in GHG intensity into a *sectoral intensity effect* and a *sector mix effect*.

Let E_t^k be the total emissions from sector k and Y_t^k be its output at time t. The sectoral emission intensity within sector k is denoted $I_t^k = E_t^k / Y_t^k$ and the sectoral share of total production is denoted $S_t^k = Y_t^k / Y_t$ where $Y_t = \sum_{k=1}^{n} Y_t^k$ is total industry output. Aggregate emission intensity is written as

$$I_t = \frac{E_t}{Y_t} = \sum_{k=1}^{n} \frac{E_t^k}{Y_t^k}\frac{Y_t^k}{Y_t} = \sum_{k=1}^{n} I_t^k S_t^k . \qquad (1)$$

Hence aggregate emission intensity is influenced by changes in the sectoral emission intensity and changes in product mix. Following Choi and Ang (2003), the two effects can be separated using equation (2):

$$\frac{I_t}{I_0} - 1 = \frac{1}{I_0}\sum_{k=1}^{n} \frac{L(I_t^k S_t^k, I_0^k S_0^k)}{L(I_t^k, I_0^k)}(I_t^k - I_0^k) + \frac{1}{I_0}\sum_{k=1}^{n} \frac{L(I_t^k S_t^k, I_0^k S_0^k)}{L(S_t^k, S_0^k)}(S_t^k - S_0^k) \qquad (2)$$

where L is the log-mean function

$L(a,b) = \frac{(a-b)}{(\ln a - \ln b)}$ if a b , L(a,b) = a if a = b.

The left-hand side of equation (2) gives us the relative change in average intensities between time t and time zero for the sectors under analysis. The first part on the right-hand side is the relative change in intensities attributed to changing sectoral intensities, which captures changes in production techniques that alter the GHG emissions in individual sectors. The sectoral intensity effect is a weighted average of these sectoral intensity changes using sectoral shares of production as weights. For instance, GHG intensity increased by 22 percent in the electric power generation sector but fell by 41 percent in the pulp and paper sector (see Table 2). Since the electric power generation sector is about three times larger than pulp and paper, the average sectoral intensity rises.

The second part on the right-hand side of equation (2) is the relative change in intensities attributed to changes in the relative size of sectors. It captures changes in the composition of industrial structure that, holding sectoral intensities constant, alter average intensities. The sector mix effect is a weighted average of sectoral share changes using sectoral intensities as weights. For instance, the oil and gas extraction sector has grown by 42 percent while electric power generation has grown by only 9 percent. Since emission intensities are higher in the electric power generation sector, its relatively slower growth will reduce average intensities.

We use sectoral data for the targeted sectors in Canada and comparison sectors in the UK to decompose the total change in aggregate GHG intensity into sectoral intensity and sector mix effects. We look at both energy intensity and GHG intensity. Canadian data are supplied by Statistics Canada using the North American Industry Classification System (NAICS). Statistics Canada reports energy use (in terajoules), greenhouse gas emissions (in kilotonnes of carbon dioxide equivalents), and output in millions of real (1997) dollars for 117 private and public sectors for 1990 to 2002. UK data come from the Office for National Statistics, Environmental Accounts. The UK data cover 76 sectors from 1990 to 2003 and provide information on output, emissions, and energy use.[4]

Both GHG data sets come from the UNFCC GHG inventory reports as required under the Kyoto Protocol. Data are collected at the plant level to estimate industry intensity and are then scaled by industry output to get total sectoral emissions. Ideally one

TABLE 2
Canadian Output, Emissions, and Intensities in the Targeted Sectors, 1990–2002

NAICS Sector	1990 Output	1990 GHG Emissions (kt)	1990 Energy Intensity (TJ/$C)	1990 GHG Intensity (kt/$C)	Growth to 2002 (% change) Output	Growth to 2002 (% change) GHG	Growth to 2002 (% change) Energy Intensity	Growth to 2002 (% change) GHG Intensity
Petroleum and coal products manufacturing	1,517	22,551	232.61	14.866	27	15	–16	–10
Pesticide, fertilizer, and other agricultural chemicals	828	7,453	44.50	9.001	10	27	35	16
Resin, synthetic rubber, and fibres and filaments	1,332	11,779	18.91	8.843	137	–78	–50	–91
Cement and concrete product manufacturing	1,972	10,044	37.14	5.093	22	13	–22	–7
Electric power generation, transmission, and distribution	20,049	92,442	59.78	4.611	9	33	29	22
Oil and gas extraction	15,796	60,350	39.01	3.821	42	65	22	16
Basic chemical manufacturing	3,431	9,960	46.60	2.903	14	–39	–25	–46
Coal mining	1,105	3,153	18.44	2.853	6	–38	–30	–41
Primary metal manufacturing	7,905	22,329	58.72	2.825	51	6	–26	–30
Miscellaneous non-metallic mineral product manufacturing	1,883	4,814	29.36	2.557	37	–8	–28	–33
Pulp, paper, and paperboard mills	7,780	13,945	50.54	1.792	13	–34	–15	–41
Non-metallic mineral mining and quarrying	2,185	1,993	20.69	0.912	51	17	–29	–23
Metal ore mining	5,739	4,214	18.15	0.734	–12	–21	–16	–10
Support activities for mining and oil and gas extraction	2,372	1,529	10.68	0.645	83	71	–5	–7
Forestry and logging	5,739	3,175	5.67	0.553	11	–13	–2	–22
Rubber product manufacturing	1,261	389	7.87	0.308	86	10	–32	–41
Converted paper product manufacturing	2,012	505	5.79	0.251	45	10	–18	–24
Miscellaneous chemical product manufacturing	3,764	912	4.81	0.242	2	–49	–35	–50
Plastic product manufacturing	3,205	643	6.37	0.201	136	–21	–47	–67
Support activities for agriculture and forestry	2,011	378	2.75	0.188	–26	128	182	207
Wood product manufacturing	7,759	1,436	5.40	0.185	53	70	34	12
Pharmaceutical and medicine manufacturing	1,805	309	2.35	0.171	122	–51	–51	–78
SUBTOTAL	**101,450**	**274,303**	**36.62**	**2.704**	**32**	**22**	**–3**	**–8**

Note: NAICS = North American Industry Classification System. GHG = greenhouse gas. Output is measured in millions of constant 1997 Canadian dollars. Energy is measured in terajoules (TJ) and GHG emissions in kilotonnes of CO2 equivalent.

Source: Statistics Canada (1990–2002) Table 153-0032, Table 153-0034, and Table 379-0017; and authors' calculations.

would like the raw plant-level data, but these are confidential. The decomposition method recaptures, to some extent, these original emission intensities, although it cannot recapture intensities at greater levels of disaggregation.

A feature of the decomposition approach used here is that changes in sectoral intensity might actually capture some intrasectoral composition effects. That is, the distribution of output within a sector changes over time as individual plants expand or contract. This will lead to changes in average emissions intensity even though there may be no changes in techniques used at the plant level. For instance, this effect is likely to occur in the power generation sector. Nuclear power and hydroelectricity are "green" in terms of GHG emissions but, due to aging plants and limited capacity to find new hydropower sites, are playing a smaller role in providing energy. In Canada, these two sources provided 14 percent of power in 1990 and only 12 percent in 2004. These changes in the composition of power supply will be reflected in worsening sector intensities. We would also expect to see this in the oil and gas extraction sector as production shifts from conventional oil sources to oil sands and heavy oil deposits. For other sectors, the direction of the mismeasurement depends on whether less emission-intensive plants are expanding or contracting. One requires finer detail at the plant level over time to account for changes in sectoral intensities due to intrasectoral composition changes. Since 2004, the Government of Canada has required large emitters to report their GHG emissions by plant. However, the inventory does not report plant-level output, and so changes in emission intensities are not yet available.

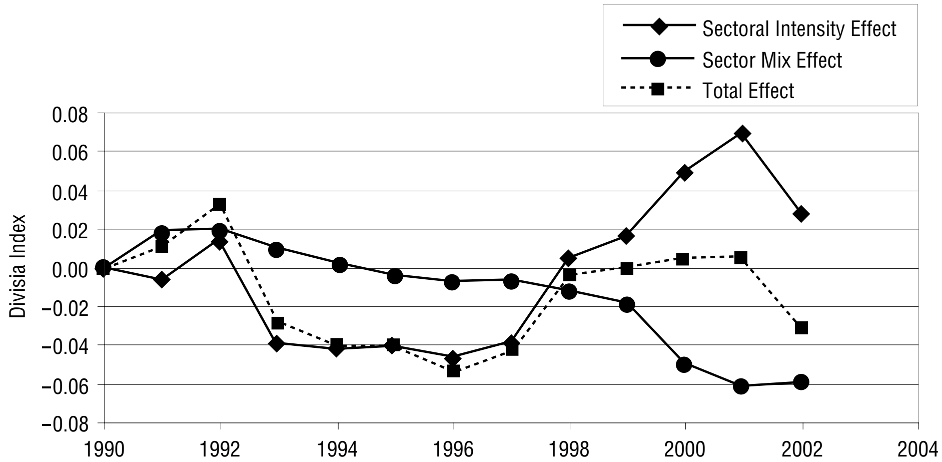
Composition and Technique Effects in GHG-Intensive Sectors: Canada

Table 1 showed that the Canadian industrial sector as a whole has reduced GHG emission intensity by about 4 percent between 1990 and 2003. We now turn to the performance of the targeted sectors between 1990 and 2002 (see Table 2). Sectors are ranked by the size of their GHG intensities in 1990. Also shown are the energy intensities for 1990. One obvious pattern that emerges is that energy-intensive sectors are also GHG intensive. Moreover, the most energy- and GHG-intensive industries are also very large. For instance, electric power generation is the largest, most polluting and, except for petroleum and coal products manufacturing, the most energy-intensive sector targeted by the regulations.

Between 1990 and 2002, all but two sectors expanded with average real economic growth at 32 percent or 2.35 percent per annum. GHG emissions rose by 22 percent or 1.65 percent per annum. At the same time, virtually all of the sectors reduced their energy and emission intensity. However, the two largest GHG emitters, the oil and gas extraction sector and the electric power generation, transmission and distribution sector, actually saw a rise in both intensities over the period. In fact, the five sectors that saw a rise in energy intensity also saw a rise in GHG intensity. Table 2 also shows that the sectors expanded at different rates and each had different changes in its emission intensities. Energy intensity decreased by 3 percent on average, and GHG intensity decreased by 8 percent.

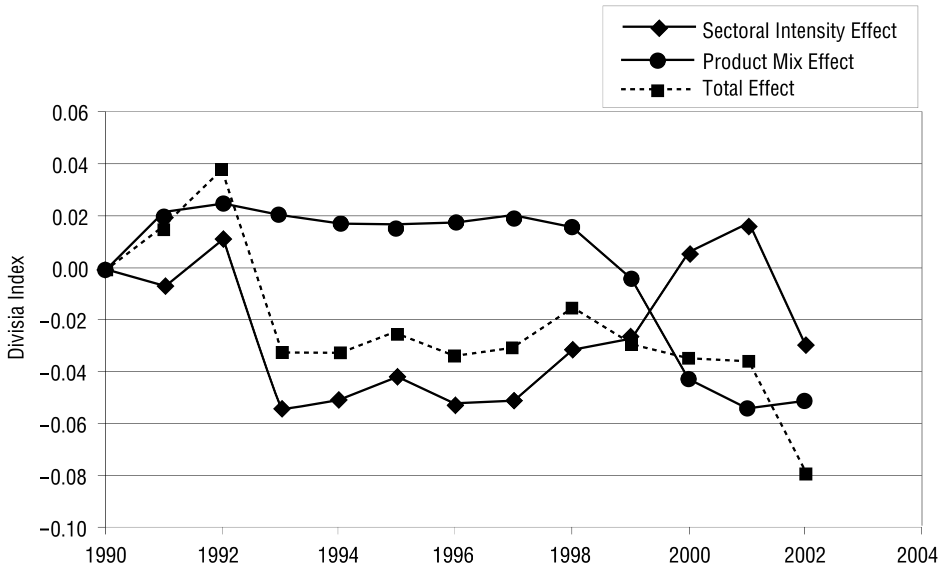
We decompose the average change in energy and GHG intensities into their separate sectoral intensity and sector mix effects using equation (2). The results are plotted in Figures 1 and 2. The sectoral intensity effect for energy shows an improvement from 1990 to 1996 but a reversal to 2001 so that, by 2002, after accounting for sector mix effects, energy intensity was about 3 percent higher than in 1990.[5] Offsetting this was a compositional shift of 6 percent toward less energy-intensive sectors. GHG sectoral intensities improved to 1996 then worsened through to 2001 but, by 2002, have improved by 3 percent from 1990 levels. At the same time the sector mix effect also improved by about 5 percent so that the average GHG intensity of the targeted sectors improved by a net 8 percent.

Figure 1
Energy Intensities in Targeted Sectors: Canada 1990–2002



Source: Statistics Canada (1990–2002) Table 153-0032, Table 153-0034, and Table 379-0017; and authors' calculations.

Figure 2
GHG Intensities in Targeted Sectors: Canada 1990–2002



Source: Statistics Canada (1990–2002) Table 153-0032, Table 153-0034, and Table 379-0017; and authors' calculations.

Figure 2 shows that sectoral intensity effects in GHG emissions exhibit a very similar pattern to that of energy intensity but are not determined solely by it. If energy use were the only factor determining GHG emissions, then the two decomposition exercises would generate identical results. However, the sectoral GHG-intensity effect shows a decrease of 3 percent rather than the 3 percent increase we see in sectoral energy intensity. This suggests that changes in production techniques have taken place in the targeted sectors that have led to reductions in GHG intensities. Nonetheless, most of the observed changes in GHG intensity can be attributed to changing composition of production.

Composition and GHG Techniques in GHG-Intensive Sectors: The UK

To evaluate the performance of Canada, we can look at how the UK has performed over the same period as a benchmark. We use the UK as it is the only country that, like Canada, publishes detailed sectoral accounts. The industrial classifications used in the two countries are not identical but are sufficiently close to allow us to make a meaningful comparison of emission and energy intensities for the targeted sectors. Though other countries also collect detailed sectoral data, they do not make this information publicly available and report only highly aggregated summaries.

It is important to note that the UK has committed, under the Kyoto Protocol, to about the same proportionate emission reductions as has Canada but, at least in terms of its energy and industrial sectors, has met its commitment by decreasing total industrial emissions by 12 percent by 2003 (see Table 1). This achievement can be partially explained by the fact that industrial output in the UK rose only 9 percent over the period. Nonetheless, emission intensities fell by 20 percent. The UK achieved this reduction despite starting at a lower emission intensity than did Canada.

Table 3 shows the sectors in the UK that parallel the targeted sectors in Canada. We do not place much emphasis on a direct comparison of sectors across the countries because data were not collected for this purpose and do not account for differences in the relative prices of output within each economy. For instance, energy prices may be higher in the UK which, all else equal, lowers its pollution intensity relative to Canada.

Overall, economic output in these sectors fell by 11 percent in real Canadian dollar terms (though it rose by 2 percent in British pounds). In contrast to Canada, total GHG emissions in these sectors in the UK decreased by 20 percent while average GHG intensity fell by 10 percent. These reductions occurred despite a rise in average energy intensity of 42 percent. Table 3 also shows that average energy intensity in the UK sectors was less than one-third that of the comparable Canadian industries, though this difference is partially explained by the relative composition of industries. This intensity difference is consistent with energy use per unit of GDP in Canada about double that in the UK (World Resources Institute 2007).

If similar sectors in the UK have been able to achieve a 10 percent reduction in GHG intensities, despite worsening energy intensity, is it likely that the Canadian sectors can hope to achieve this as well? Figures 3 and 4 show the divisia decomposition of energy intensities and GHG intensities into their sector mix effects and sectoral intensity effects for the UK. What is immediately apparent is that improvements in energy intensity do not appear to be the driving factor in reducing GHG intensities. As illustrated, the composition of UK industry has moved slightly toward less energy-intensive sectors. On the other hand, the sectoral energy-intensity effect shows a spike upwards between 1990 and 1992. Since 1992 there has been little to no change in energy intensity with the aggregate sectoral energy intensity in 2002 about 30 percent above the 1990 levels. The UK has seen a slightly stronger shift

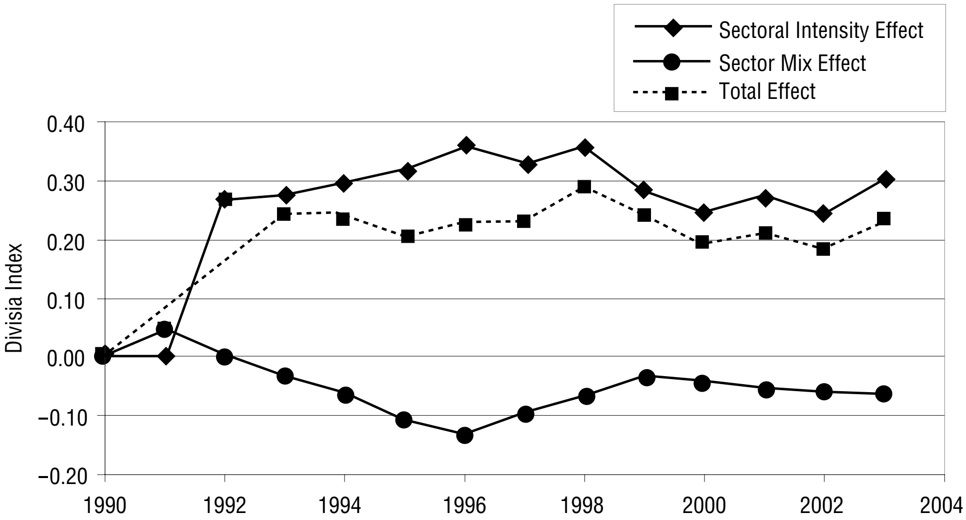
TABLE 3
UK Output, Emissions, and Intensities in the Targeted Sectors, 1990–2003

Sector	1990				Growth to 2003 (% change)			
	Output	GHG Emissions (kt)	Energy Intensity (TJ/$C)	GHG Intensity (kt/$C)	Output	GHG	Energy Intensity	GHG Intensity
Cement, lime, and plaster	2,965	15,412	34.08	5.197	–39	–32	–2	12
Organic chemicals	13,672	42,573	5.37	3.114	–3	–82	21	–82
Electricity production and distribution	68,909	201,195	36.15	2.920	–14	–9	24	6
Fertilizers	2,664	5,888	4.51	2.211	–41	–28	557	20
Coal extraction	11,412	18,594	2.57	1.629	–82	–73	30	53
Iron and steel	27,252	29,851	5.04	1.095	–52	–18	441	71
Metal ores extraction	22	17	14.17	0.793	–92	93	1,089	2,199
Coke ovens, refined petroleum, and nuclear fuel	34,641	22,562	4.50	0.651	–15	–13	267	3
Oil and gas extraction	36,788	21,672	4.42	0.589	31	13	39	–14
Man-made fibres	2,878	1,551	8.14	0.539	–63	–79	2	–42
Inorganic chemicals	3,302	1,593	7.38	0.482	–2	27	93	30
Industrial gases and dyes	5,052	1,941	4.14	0.384	–12	–33	92	–25
Plastics and synthetic resins, etc.	8,706	1,599	3.73	0.184	–15	10	27	28
Pulp and paper	26,680	4,876	3.32	0.183	–26	–16	16	14
Plastic products	26,305	4,297	2.83	0.163	11	3	18	–8
Rubber products	7,504	1,157	2.99	0.154	–19	–12	15	9
Other mining and quarrying	8,483	1,080	2.68	0.127	–2	–5	–3	–4
Non-ferrous metals	15,606	1,802	2.72	0.115	–53	83	144	288
Other chemical products	8,962	1,012	2.07	0.113	–6	–47	–35	–44
Pharmaceuticals	15,591	1,001	1.22	0.064	69	60	4	–5
Pesticides	2,477	159	1.30	0.064	–5	73	66	83
Wood and wood products	13,256	739	0.99	0.056	–3	631	528	656
Paints, varnishes, printing ink, etc.	6,556	320	1.11	0.049	–13	–35	–11	–26
Soap and toilet preparations	11,471	536	1.02	0.047	–14	–47	–27	–39
Forestry	1,128	34	0.61	0.030	29	100	70	55
SUBTOTAL	**362,283**	**381,462**	**9.91**	**1.053**	**–11**	**–20**	**42**	**–10**

Note: GHG = greenhouse gas. Output is measured in millions of constant 1997 Canadian dollars. Energy is measured in terajoules (TJ) and GHG emissions in kilotonnes of CO2 equivalent.

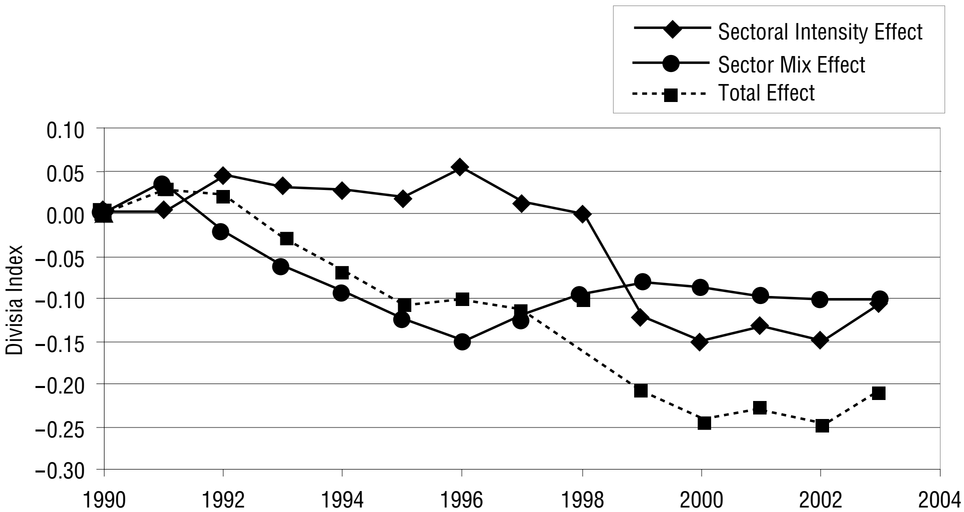
Source: UK Office for National Statistics (1990–2003). Tables 1990–76 to 2003–76, Environmental Accounts.

FIGURE 3
Energy Intensities in Targeted Sectors: UK 1990–2003



Source: UK Office for National Statistics (1990–2003) Tables 1990–76 to 2003–76, Environmental Accounts; Input-Output, UK National Accounts; and authors' calculations.

FIGURE 4
GHG Intensities in Targeted Sectors: UK 1990–2003



Source: UK Office for National Statistics (1990–2003) Tables 1990–76 to 2003–76, Environmental Accounts; Input-Output, UK National Accounts; and authors' calculations.

toward less GHG-intensive production. The sectoral intensity effect, on the other hand, shows significant improvement of about 25 percent from 1990 to 2003.

Can Canada Replicate the UK Experience?

So how can energy intensity worsen in the UK and yet GHG intensities improve so dramatically? A partial answer seems to be a switch in fuel use from a relatively heavy reliance on coal to a greater reliance on natural gas. Overall, natural gas and coal provide just over 50 percent of UK energy needs. However, in 1990, 29 percent of the energy used came from coal and 24 percent came from natural gas. By 2003, only 15 percent of the energy came from coal, while natural gas supplied 36 percent of the energy needs. Herzog, Baumert, and Pershing (2006, 6) report that 12 percent of the decline in aggregate GHG emissions in the UK comes from this changing fuel mix.

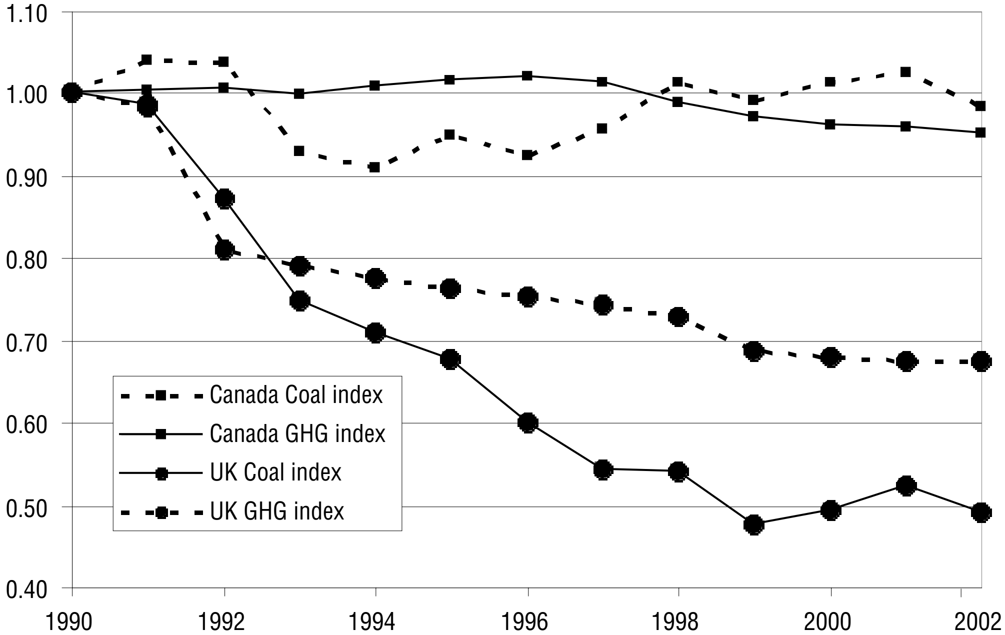
The reliance on coal and natural gas is even higher in the targeted sectors. In 1990, coal accounted for 64 percent of energy used in these sectors with natural gas contributing another 11 percent. By 2003, coal contributed 36 percent and natural gas 39 percent of the energy needs in these sectors. In electric power production alone, the reliance on coal fell from 87 percent in 1990 to 53 percent in 2004 (UK Office for National Statistics 1990–2003).

Since the GHG intensity of coal is about double that of natural gas (Natural Resources Canada 2006b), this fuel shift would reduce GHG emissions without requiring any net reduction in energy use. To see this, we generate an index of the GHG intensity of energy using 1990 as our base (see Figure 5). The GHG intensity of energy is calculated as the ratio of GHG emissions per unit of energy. By 1995, GHG emissions per unit of energy use had decreased by over 24 percent. By 2003, each unit of energy used emitted about 33 percent less GHG than it had in 1990. We can compare this to the share of coal used in energy. Taking 1990 as a base, the share of coal used in the UK had fallen 32 percent by 1995 and 52 percent by 1999. Since 1999 there has been no noticeable decrease in the share of coal as a fuel source. Though the relationship between the two series is not one-to-one, there is an obvious correlation between the two.

Can Canada hope to achieve the same success by switching fuels? In short, the answer appears to be not likely. Coal contributes less than 11 percent of total energy used in Canada. In fact, coal contributes only 30 percent of the energy used in electricity generation. Non-electric production uses coal for less than 2 percent of its energy needs (Natural Resources Canada 2006b). Since 1990, the relative share of energy sources for industry has not changed much in Canada with natural gas, the dominant fuel source, providing about 27 percent of energy needs. Figure 5 shows the change in the share of coal in Canadian energy with 1990 as the base year. Also shown is the change in the ratio of GHG emissions per unit of energy with the index for 1990 equal to 100. Unlike the UK, the share of coal in energy in Canada has not changed much, nor has the relationship between GHG emissions and energy use.

Though switching from coal to natural gas or to other greener power sources may not offer much scope for Canadian firms, this is not the only way to reduce emission intensities. There are still process innovations that are available and, most importantly, improvements in energy efficiency since most emissions derive from the combustion of carbon fuels. The energy intensity of GDP in Canada is about double that of the UK (World Resources Institute 2007). Though some, but certainly not all, of the difference could be attributed to different industrial structures, Tables 2 and 3 showed that sectoral energy intensities are much higher in Canada than in the UK. This suggests that there may

Figure 5
Coal Versus GHG Indices: UK and Canada 1990–2002



Notes: The coal index is the share of coal in total energy use relative to 1990. The GHG index is the ratio of GHG emissions to total energy use relative to 1990.

Source: UK Office for National Statistics (1990–2003) Tables 1990–76 to 2003–76, Environmental Accounts; Natural Resources Canada 2006b; Statistics Canada (1990–2002) Table 153-0032, Table 153-0034, and Table 379-0017; and authors' calculations.

be ample opportunities for Canadian firms to improve energy efficiency and so reduce GHG emissions.

Policy Scenarios

We now try to gauge the impact of the federal policy on GHG emissions and intensity relative to historical trends within the targeted sectors. We do this by building three scenarios that incorporate economic growth, intensity changes, and the proposed regulations (Table 4). Although the proposed regulation is based on 2006 emission intensities, our data only go to 2002. To capture the short four-year time frame that the proposed policy is supposed to take effect, we set the new target date at 2006 rather than 2010 and use 2002 as our base year. We assume that output in each sector grows at the same rate from 2002–2006 as it did in the 1990–2002 period. This could overestimate growth as the proposed regulations will increase production costs and might slow sectoral growth. On the other hand, firms may accelerate growth to "dilute" emissions as a way to

TABLE 4
Output Growth and GHG Credit Scenarios for Targeted Sectors

Sectors	2002 GHG (Actual)		SCENARIO 1: BAU		SCENARIO 2: Limited Credits for Past Action			SCENARIO 3: No Credits for Past Action		
	Intensity (kt/$M)	*Emissions (kt)*	*Intensity (kt/$M)*	*Emissions (kt)*	*Intensity (kt/$M)*	*GHG Reductions[a] (kt)*	*Costs[b]*	*Intensity (kt/$M)*	*GHG Reductions (kt)*	*Costs*
Petroleum and coal products manufacturing	13.448	25,981	13.006	27,237	12.404	1,261	0.90	11.027	4,144	2.97
Pesticide, fertilizer, and agricultural chemical	10.428	9,500	10.952	10,300	8.551	2,258	3.60	8.551	2,258	3.60
Electric power generation, transmission, and distribution	5.631	123,220	6.018	135,608	4.617	31,574	2.10	4.617	31,574	2.10
Cement and concrete product manufacturing	4.722	11,371	4.605	11,851	4.356	641	0.37	3.872	1,885	1.10
Oil and gas extraction	4.442	99,303	4.671	117,235	3.643	25,813	1.54	3.643	25,813	1.54
Primary metal manufacturing	1.983	23,607	1.763	24,049	1.829	–908	–0.10	1.626	1,862	0.20
Miscellaneous non-metallic mineral product	1.706	4,408	1.491	4,280	1.573	–238	–0.12	1.399	264	0.14
Coal mining	1.690	1,970	1.419	1,684	1.558	–166	–0.21	1.385	40	0.05
Basic chemical manufacturing	1.559	6,117	1.267	5,200	1.438	–700	–0.26	1.279	–46	–0.02
Pulp, paper, and paperboard mills	1.055	9,256	0.884	8,074	0.973	–814	–0.13	0.865	173	0.03
Resin, synthetic rubber, and artificial and synthetic fibres and filaments	0.819	2,587	0.371	1,561	0.756	–1,621	–0.58	0.672	–1,268	–0.45
Non-metallic mineral mining and quarrying	0.704	2,327	0.646	2,450	0.649	–13	–0.01	0.577	260	0.10
Metal ore mining	0.657	3,313	0.634	3,058	0.606	132	0.04	0.539	456	0.14
Support activities for mining and oil and gas	0.600	2,610	0.586	3,119	0.554	173	0.05	0.492	500	0.14
Support activities for agriculture and forestry	0.577	863	0.838	1,136	0.473	495	0.55	0.473	495	0.55
Forestry and logging	0.432	2,766	0.398	2,642	0.399	–4	0.00	0.355	290	0.07
Wood product manufacturing	0.206	2,446	0.214	2,921	0.169	611	0.07	0.169	611	0.07
Converted paper product manufacturing	0.190	554	0.173	571	0.175	–7	0.00	0.156	57	0.03
Rubber product manufacturing	0.182	427	0.153	440	0.168	–44	–0.02	0.149	10	0.01
Miscellaneous chemical product manufacturing	0.120	462	0.095	368	0.111	–61	–0.02	0.099	–13	–0.01
Plastic product manufacturing	0.067	505	0.046	466	0.062	–154	–0.02	0.055	–85	–0.01
Pharmaceutical and medicine manufacturing	0.038	152	0.023	120	0.035	–63	–0.02	0.031	–43	–0.01
SUBTOTAL	**2.489**	**333,745**	**2.440**	**364,372**	**2.051**	**58,167**	**0.58**	**1.977**	**69,238**	**0.70**
Growth since 2002			–0.019	0.092	–0.176			–0.206		

Notes: GHG = greenhouse gas. BAU = business as usual.

[a] GHG reductions are from BAU emissions.

[b] Costs are expressed as a share of sectoral GDP in 2002 assuming $15 per tonne of reductions.

Source: Statistics Canada (1990–2002) Table 153-0032, Table 153-0034, and Table 379-0017; and authors' calculations.

meet intensity targets. This dilution still requires changes in techniques to achieve reductions in intensity toward the target. However, as we argue below, the net cost of the initial regulation phase is a relatively small share of sectoral value added and therefore is unlikely to influence production decisions too much. Exogenous demand and supply conditions would likely remain the dominant factors influencing production.

In our first scenario, we assume a business-as-usual (BAU) situation in which sectoral output and GHG emissions grow between 2002 and 2006 at the same rate as they did between 1990 and 2002. On average, 2006 real sectoral GDP would be 11 percent higher than 2002 values and 47 percent above 1990 values. This growth rate implies that GHG emissions would rise by 9 percent or 30,000 kilotonnes in four years. This is 33 percent above 1990 levels. Emission intensity under BAU falls by 2 percent to 2.440 in the transition period. To meet the Kyoto targets by changes in output alone would entail a decrease in sectoral GDP of about 19 percent from 2002 levels. This first scenario provides a baseline for the remaining ones.

In our second scenario, we assume that the government allows a one-time credit for previous GHG reductions. The government intends to limit credits for early action to 15,000 kilotonnes (just under 5 percent of 2002 emissions in the regulated sectors). Depending on how this policy is interpreted and implemented, it is possible that a sector, based on previous performance, will meet the new targets without any action (at least initially). From Table 2 we see that about half of the sectors have seen decreases in emission intensities in excess of 18 percent since 1990. The sectors that saw a fall in intensities account for about 27 percent of sectoral emissions and a reduction in total emissions of about 14,000 kilotonnes between 1990 and 2002. This decrease in emissions is just below the government's allowable limit for credits for early action. Hence, the majority of emissions in the regulated sectors will still need to be reduced so that each sector meets its intensity target. To incorporate this one-time credit possibility, we assume that all sectors that have seen a rise in emission intensities between 1990 and 2002 must reduce intensities by 18 percent in the four years. Those sectors that have seen a decrease in intensities between 1990 and 2002 will have to reduce intensities by 2 percent per annum. This 2 percent represents the target reduction that follows the initial four-year transition phase. For many sectors this is a slower rate than they have experienced in the past.

Based on these assumptions, emission intensities would fall to an average of 2.051, a weighted average decrease of 18 percent in four years. Assuming each sector meets its intensity targets, total GHG emissions after four years would be 8 percent below the 2002 level (or 27,000 kilotonnes lower) *but still 12 percent above the 1990 levels.* To meet Kyoto targets in the four years would require an additional fall in intensities of about another 10 percent. Nonetheless, emissions are about 16 percent below BAU (or 58,000 kilotonnes). Hence even if the credit allocations are generous, the proposed targets still constrain behaviour since the largest emitters would likely not receive any credits for past actions. Note that for 11 sectors the target reduction of 2 percent per annum is below their decreases under BAU and so would allow them to sell emission permits to other firms.

If we assume that facilities take a business-as-usual approach and simply buy credits, then, to meet the targets, firms would have to pay for about 60,000 kt of emissions not abated. The proposed cost per tonne for contributions to the climate change technology fund is set at \$15. Therefore, the cost of paying for credits rather than reducing emissions is less than \$1 billion for the transition period alone (see Table 4). This is about 0.6 percent of GDP in the target sectors in 2002 though spread over a number of years. Note that some sectors will generate revenues from selling GHG credits and that the maximum impact of the proposal is above 1 percent of sectoral value added in only three sectors. Of course, facilities would undertake investments in processing, energy efficiency, fuel switching, and technological innovation if these cost less than $15 per tonne of GHG reduction. Overall, the implied cost of failing to reduce emissions is relatively small, and so it is likely that many firms will choose to pay rather than abate. To what extent firms choose to pay rather than abate depends on abatement opportunities faced by individual firms. Available public data do not allow us to assess this.

For our third scenario, we again take 2002 as our base year but assume that facilities are not credited with reductions for early action. Hence every sector must individually reduce intensities by 18 percent in the four-year transition period or purchase credits from other sectors. This policy would force the maximal change in sectoral performance. Total GHG emissions would fall by 12 percent in the four years. Intensities would fall to 1.997 for an average decrease of 21 percent. Total emissions *would still be 8 percent above 1990 levels* but 19 percent below BAU (or 70,000 kilotonnes). The net cost of this scenario is still below 1 percent of sectoral GDP.

These scenarios suggest that the outcomes of the policy could sever the linkage between economic growth and GHG emissions; the outcomes are certainly a break from business as usual. The difference between the second and third scenarios is less than the allowable credit for early action and, in terms of BAU, not much different. Hence providing credits for past actions is not a significant factor in reducing total emissions. Between 1990 and 2002 economic growth in the regulated sectors was around 32 percent while emission growth was 22 percent. If the policy is implemented, economic growth could continue (by assumption) while GHG emissions would fall between 8 and 12 percent. This reduction would be significantly below BAU emission levels. Although GHG intensities did fall 8 percent between 1990 and 2002, implementation of the new policy would ensure that new intensities would fall an additional 18 to 21 percent in only four years. This decrease in intensities is *almost 7 times faster* on an annual basis than experienced in the 1990–2002 period. Importantly, *it is about 6 times more than achieved by changes in techniques alone over the entire 1990–2002 period*. Nonetheless, implementation costs, assuming a cost of $15 per tonne of emissions, are modest.

Discussion

The Government of Canada's proposal to limit GHG emissions by targeted reductions in emission intensities in selected industries does not constitute business as usual. If the proposal is implemented, GHG emissions in these sectors will likely, after rising from 1990 to 2002, begin to fall. However, the rate of decrease will still leave emissions much higher than 1990 levels and therefore move us only partially toward complying with our Kyoto commitments. Further, the subsequent reductions in intensities of 2 percent per annum may only just offset real growth in these sectors since real output averaged an annual growth rate of 2.35 percent between 1990 and 2002. In this respect the proposal is not overly ambitious, though it does move us somewhat toward meeting our Kyoto commitments.

On the other hand, the proposal is ambitious in that the relatively short implementation period would force plants to reduce emission intensities at much higher rates than previously seen in Canada, or in many other countries for that matter. GHG intensity in the targeted sectors fell by 8 percent between 1990 and 2002 but would have to fall somewhere in the range of 18 to 21 percent in only four years to meet the new targets. This pace is about seven times faster than the rate of improvement in 1990–2002. However, to meet our Kyoto commitments of a 6 percent decrease in GHG emissions would require a decrease in emission intensities of about 26 percent, which implies an acceleration in the decrease in intensities almost ten times faster than the historical trend.

The sharp reduction in intensity required leads to the possibility that facilities may not be able to meet their intensity targets by in-house technological improvements alone. Evidence from Canada and the UK shows that changes in the techniques of production between 1990 and 2002 have had only a small impact on emission intensities. Cole, Elliott, and Shimamoto (2005, 66) also find the same result for CO2 emissions in Austria, France, the Netherlands, and the UK. A primary driver in all these countries in reducing GHG or CO2 intensities has been a reallocation of production to less pollution-intensive industries. As the proposed regulations do not provide credits for sectors that reduce output for economic reasons, Canadian firms will not have this avenue available to them. Plants may find even these modest targets (relative to our Kyoto commitments) difficult to meet by innovation alone as meeting the targets would entail an acceleration in innovation by about six times more than that achieved over the entire 1990–2002 period. On the other hand, past environmental regulations with respect to GHG emissions in most countries have been weak, and so firms have not been forced to alter production techniques much. Most Organisation for Economic Co-operation and Development countries have much lower industrial GHG intensities than does Canada. Whether Canadian firms can achieve the same absolute levels of emission intensity or reductions in intensity depends on the regulations creating significant incentives. Given the modest cost of paying for credits to meet the proposed obligations, it remains an open question whether these incentives are strong enough.

Thus, the proposed regulations, if implemented and if facilities can meet the new intensity targets, would constitute a distinct break from past emission performance. The new targets, however, do not appear sufficient to meet our current Kyoto targets and, given that the sectors have been growing at an average of over 2 percent per annum, Canadian businesses are unlikely to meet these new targets in the future.

Notes

[1] Ideally, we would like to compare the performance in other countries as well. However, detailed sectoral data are not readily available in other countries and therefore decomposition for the targeted sectors is not possible.

[2] According to Environment Canada (2008), the CO2 equivalence per kilowatt hour of electricity generated in 2005 is almost double for coal thermal generation compared with natural gas generation (994 $g\ CO_2\ eq/kWh$ vs 503).

[3] In some cases, such as for calcination in cement and lime production, there is no known abatement process. Emissions from these sources, however, will be exempted from regulations (Government of Canada 2007, 11).

[4] The United Kingdom reports energy use in tonnes of oil equivalent (TOE). These are converted to terajoules using a conversion factor of one TOE per 41.868 terajoules. UK output is first deflated into constant UK pounds using the Producer Price Index for Manufacturing (Series PPI: 7209200000). The pounds are then converted to constant 1997 Canadian dollars using purchasing power parity (PPP) exchange rates taken from the PENN World Tables version 6.2 (Heston, Summers, and Aten 2006). Specific sectoral price indices are not available until 1991 so not all intersectoral price changes will be captured in the decomposition. However, using 1992 as a base and using sector-specific price indices does alter the overall pattern of changes in the product mix and sectoral intensity effects.

[5] Although energy use per dollar of output has risen, this does not necessarily mean that energy efficiency, in an engineering sense, has worsened. In fact, Natural Resources Canada (2006a) reports that energy efficiency gains would have reduced energy use by 13 percent between 1990 and 2004.

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