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Accounting for Greenhouse Gases in the Standard Productivity Framework

by Tarek M. Harchaoui, Dmitry Kabrelyan and Rob Smith

Micro-Economic Analysis Division
24-B, R.H. Coats Building, Ottawa, K1A 0T6

Telephone: 1 800 263-1136

This paper represents the views of the authors and does not necessarily reflect the opinions of Statistics Canada.

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Ottawa, K1A 0T6
Statistics Canada

How to obtain more information:
National inquiries line: 1 800 263-1136
E-Mail inquiries: infostats@statcan.ca

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The authors' names are listed alphabetically.

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Table of Contents

Abstract

The method that Canada and other developed countries use to measure productivity growth generally ignores the pollutants that are produced by the industrial process. For example, greenhouse gas emissions, though an inevitable consequence of production processes, are excluded from the productivity accounting framework. This study proposes an extended productivity measure that takes pollutants into account. It illustrates how it can be applied using carbon dioxide emissions. The proposed experimental measure is based on the standard multifactor productivity framework adjusted for the private cost of greenhouse gas emissions. Using this measure changes the estimate of productivity growth for the business sector. The paper first examines how industries have reduced their CO_2 emissions relative to their saleable outputs over the last twenty years. This improvement is a form of efficiency gain. When this is taken into account using the new experimental methodology to estimate multifactor productivity, the estimate of productivity growth that is produced is about 17 percent higher than the conventional estimate over the period from 1981-1996.

Keywords: productivity, environment, eco-efficiency, CO_2

Executive Summary

In the industrialized world over the past century, progress has often been measured in terms of economic efficiency and growth. Adverse environmental, social and health impacts of economic change have rarely been tallied up as costs. This paper proposes an experimental productivity measure that allows for environmental effects, illustrates how it can be measured and shows the impact on the productivity performance of the Canadian business sector over the 1981-1996 period.

More specifically, the paper discusses five sets of questions:

1) How is multifactor productivity currently being measured?

   Productivity, which measures the efficiency with which firms transform inputs (capital, labour, materials and services) into products, is one of the key economic performance indicators. It is measured as the growth rate of outputs minus the rate of growth of combined inputs.

   The methodology and the data used to calculate these productivity measures have been improved recently. The measurement of labour inputs now distinguishes between categories of labour whose effect on productivity differs because of differences in educational attainment or accumulated experience. The measurement of capital input takes into account differences in the amount of services yielded by different types of equipment and structures.

   Despite this progress, conventional measures of productivity growth still ignore unpriced outputs like pollution. Processing and fabrication of commodities generates several hundred million tonnes of wastes and effluents that are discharged into the environment each year.

2) Can the existing productivity framework be amended to accommodate eco-efficiency, that is, the extent to which the economic activity is efficient in terms of its use of the environment as an input?

   Yes. An extension of the current productivity framework is proposed and implemented in this paper. The proposed experimental measure, which builds on the current productivity framework, includes as output both goods and services that are marketed as well as the pollution that businesses produce as a by-product.

   Calculating the new productivity measure requires an estimate of the cost of emissions. It is measured in this study as the private costs that have resulted from changing the level of emissions in the past.

3) What is the trend in the change of emissions relative to marketed outputs reported by Canadian industries?

   A case study of the gains in environmental efficiency in several major Canadian industries is included in the paper, using greenhouse gases as an example. Over the years, many industries have reduced their emissions relative to their marketed outputs. Outputs have grown more quickly than emissions and thus the productivity with which the environment has been used (as measured by output per unit of emissions) has increased.

4) What are the sources of growth behind gains in this partial productivity indicator?

   Over the 1981-1996 period, the greenhouse gases per unit of marketed output experienced a 0.9 percent decline on average, a form of efficiency gain. The change in the greenhouse gases per unit of marketed output can be decomposed into changes in two underlying components: 1) the greenhouse gases per unit of energy consumption and 2) the energy consumption per unit of marketed output. Greenhouse gases per unit of energy increased by 0.8 percent annually. This was offset by a 1.7 percent decrease in the energy per unit of marketed output.

5) Does the productivity performance record of Canadian businesses change once greenhouse gases are accounted for in the current productivity framework?

   Yes. The revised methodology takes into account a source of productivity growth that the conventional methodology misses: a more rapid growth in the value of total output due to a shift toward highly valued marketable products and away from negatively valued waste products. This is as important an efficiency gain as any other. In the manufacturing sector, it has been an important source of productivity improvement.

   According to the conventional measurement, average productivity growth in the Canadian industries studied here increased from 1981 through 1996 at an annual average rate of 0.77 percent per year. After taking account of the increase in the output per unit of greenhouse gas emissions, the revised record shows that productivity grew at 0.90 percent per year—a 17 percent increase over the conventional measure.

I. Introduction

Productivity—the efficiency with which the economy transforms inputs into outputs—is important because it largely determines real incomes. Canadian living standards are high not only because workers have more equipment and resources to work with, but also because Canadian businesses have learned to use labour and other resources more efficiently.

Productivity can be measured in different ways: labour productivity measures output per hour worked; multifactor productivity—a broader indicator—measures the productive efficiency of labour, capital, and other inputs that are used in combination one with another. Either way, productivity measures provide a key indicator of the progress that businesses have made with regards to technological and organizational efficiency.

Over time, the productivity growth rate determines how fast real incomes can rise. If the availability of goods and services were limited entirely by the gradual increase in the labour force and capital stock, then Canadian living standards today would not be as high as they are. For example, from 1961 through 1999, Canadian agricultural output rose at an average annual rate of 3.7 percent, though overall input use actually declined (-0.02% for capital input and -1.5% for labour input). Rapid productivity gains made the difference.

Measures of productivity tell us how much more rapidly output is growing than the resources that are applied to the production process. Normally these measures take account only of marketed goods and services. They do not consider pollutants that are produced alongside goods that are sold to consumers and producers. In this paper, we take a first step to overcome this deficiency.

II. How is Productivity Currently Measured?

Until 1987, Statistics Canada focused only on labour productivity and measured it as output per employee.[1] More recently, it recognized the increasing importance of part-time work and moved to make use of the number of hours worked rather than just number of workers.

A measure of labour productivity reflects not only changes in technology and the reallocation of labour to higher-valued industries, but also changes in the availability of capital per hour—a result of capital accumulation. Labour productivity takes into account the efficiency with which only one factor of production (labour) is transformed into output. As such, it is referred to as a 'partial' productivity measure. Other such 'partial' measures can be constructed—output per unit of capital, output per unit of materials used, or output per unit of energy consumed. Each of these captures the extent to which the production process is becoming more efficient in terms of its use of that particular factor.

[1] For an overview of Statistics Canada's productivity program, see Harchaoui *et al.* (2001).

In order to jointly consider all inputs together, Statistics Canada has followed the recommendation of economists and introduced a broader measure. Known as a multifactor productivity measure, it is meant to capture the efficiency with which several inputs are used—capital and materials as well as labour. The growth in multifactor productivity is defined as the difference in the rate of growth of output minus the rate of growth of a weighted sum of all inputs. A multifactor productivity growth measure captures the increase in output beyond that explained by mere increases in inputs. This increase is attributable to technological and organizational advance.

Much time and energy has been devoted to improving the methodology and the data used to calculate these productivity indicators. The measurement of labour input has been modified to distinguish between categories of labour whose effect on productivity differs because of educational attainment or accumulated experience (see Gu *et al*. 2002). The measurement of capital input has been revisited to take account of differences in the composition of capital in terms of various categories (see Harchaoui and Tarkhani 2002). Finally, the measurement of output has been improved by distinguishing quality improvements from quantitative increases in the output of goods and services.

The conventional measures of productivity growth consider only outputs and inputs that are priced in markets. They ignore non-priced outputs such as greenhouse gases. The remainder of this paper explains how this omission affects estimates of the productivity performance of the business sector. The paper then proposes an experimental framework for broadening multifactor productivity to a 'multi-resources' productivity measure, an indicator useful for studies of sustainable development. The proposed framework, which is analogous to the concept of total resource productivity recently suggested by Gollop and Swinand (2001), is merely the standard multifactor productivity framework adjusted for the environmental impacts of emissions of bad outputs. Our results, based on Canadian business sector data over the 1981-1996 period, indicate that ignoring environmental effects can introduce a downward bias to the standard measure of productivity performance. The new experimental estimates presented in this paper are higher than the conventional ones that exclude greenhouse gas emissions.[2]

[2] This is also what Gollop and Swinand (2001) found in their study of the US agricultural sector during the 1973-1993 period.

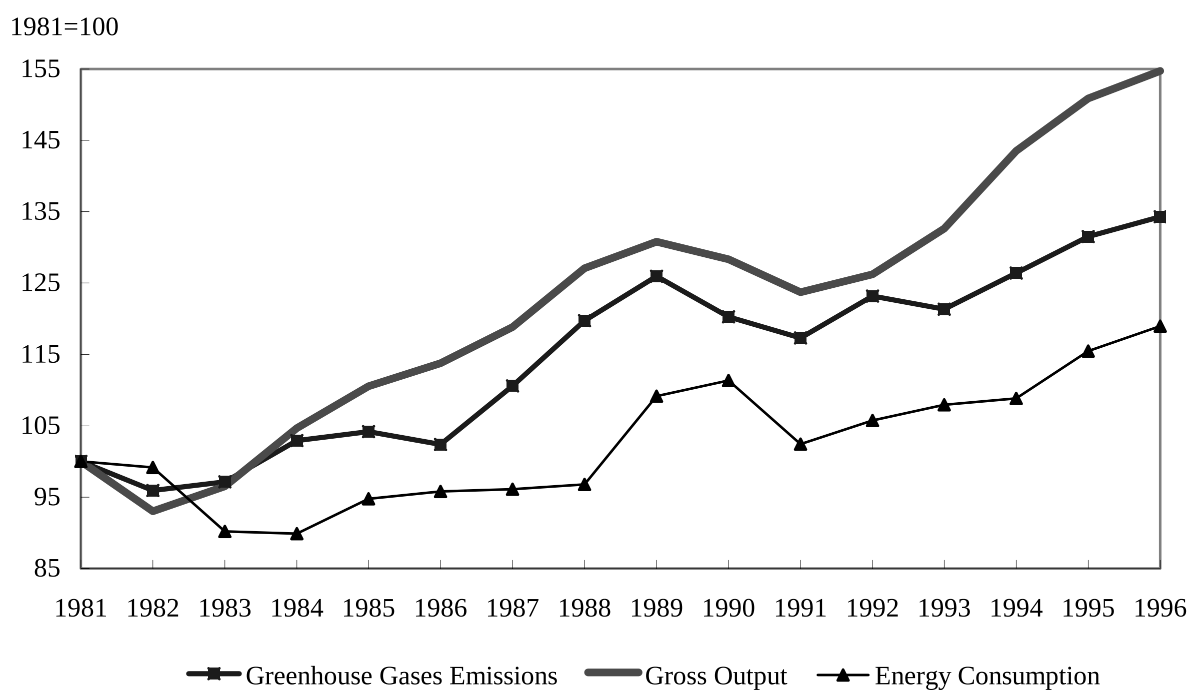
III. How Can the Conventional Productivity Framework be Extended?

1. The Technology Specification: Joint-Products or Mono-Products?

The conventional productivity measure only imperfectly captures industrial processes. Industries transform material and energy inputs into marketed outputs. These transformations conform to physical laws, including the conservation of matter and energy, which dictates that all the raw materials drawn into an industrial process re-emerge in some form. An industrial engineer can lay out a materials and energy balance for any industrial process, showing that all the inputs go somewhere, some to product and some to waste streams.

For example, a typical 500-megawatt coal-fired power station produces not only 3.5 billion kilowatt hours of electricity per year—the measured ‘output’—but also 5,000 tonnes of sulphur oxides, 10,000 tonnes of nitrogen oxides, 500 tonnes of particulate matter, 225 pounds of arsenic, 4.1 pounds of cadmium, and 114 pounds of lead, as well as trace amounts of other minerals embedded in the coal. All the 1.5 million tonnes of coal burned each year in the power station end up as ashes, emissions, and other waste products, including more than a million tonnes of carbon, virtually all of which is emitted as carbon dioxide. The plant also generates a good deal of waste heat, which is usually dispersed in cooling waters.

Figure 1. Growth Pattern of Greenhouse Gases, Energy Consumption and Output



Processing and fabrication of commodities generates several hundred million tonnes of wastes and effluents that are discharged into the environment. Ignoring greenhouse gases is by no means a trivial omission. In 1996, to produce nearly $ 480 million of output, the Canadian business sector generated 386 million tonnes of greenhouse gases.[3] With an average annual growth of 2 percent over the 1981-1996 period, the Canadian business sector production of greenhouse gases tracks closely the pattern of economic growth and energy consumption, which experienced, respectively, 3 percent and 1.2 percent increases over the same period (Figure 1).

Energy consumption in the form of fossil fuel combustion is the largest single contributor to greenhouse gas emissions in Canada and the world (70.2 percent in 1996).[4] In 1996, the largest sources of energy consumption in the Canadian business sector were natural gas (32 percent), followed far behind by electricity (19 percent) and diesel fuel (11 percent). The last fifteen years witnessed a major shift in energy generation sources away from oil and heavy fuels toward natural gas, mainly as a result of a number of factors, including availability, favourable pricing and potential for increased efficiency (Figure 2). Generally, greenhouse gases discharged from natural-gas-fired generators are less than those from oil-fired generators; therefore, the shift in fuel sources caused a reduction in combustion emissions intensity over the period.

In the short term, year-to-year changes in energy consumption and carbon dioxide emissions tend to be dominated by weather, economic fluctuations, and movements in energy prices. Over longer time spans, changes in energy consumption and emissions are influenced by other factors such as energy consumers' choice of fuels, appliances, and capital equipment (e.g., vehicles, aircraft, and industrial plant and equipment). Changes in the efficiency of energy consumption happen gradually because the energy-consuming capital stock of the Canadian business sector—cars and trucks, airplanes, heating and cooling plants in businesses, steel mills, aluminum smelters, cement plants, and petroleum refineries—changes slowly from one year to another, because capital stock is retired only as it begins to break down or becomes obsolete.

Over the last fifteen years, energy consumption, like emissions, has grown relatively slowly, with year-to-year fluctuations in the growth rate of energy consumption largely caused by the business cycle and the weather.

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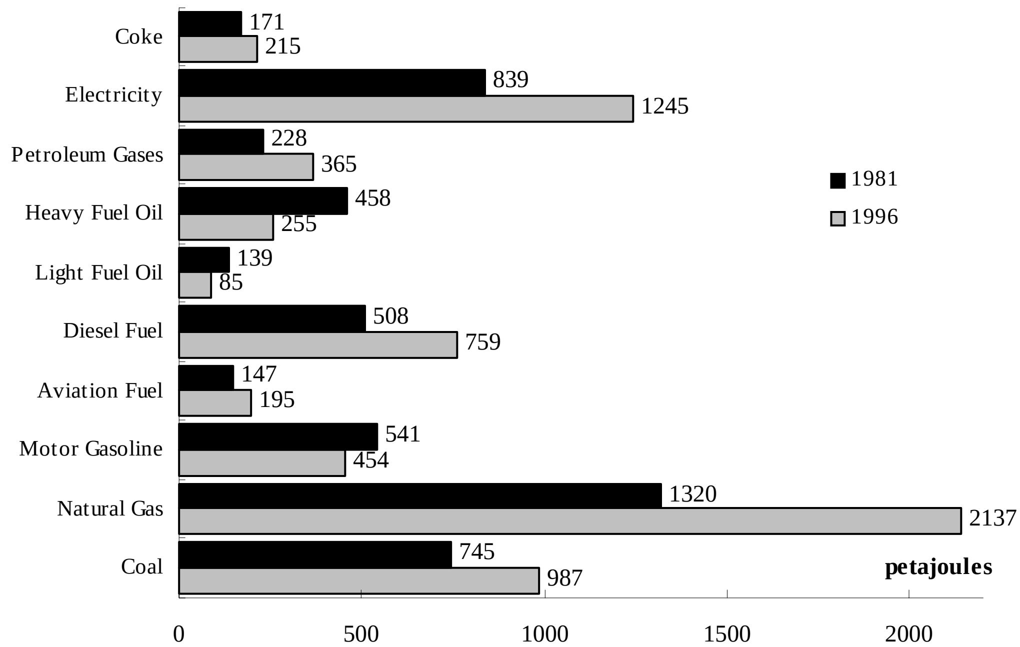
[3] The concept of business sector used in this paper is narrower than the one traditionally used by the productivity program of Statistics Canada. The following industries have been excluded from the usual definition of business sector: finance and real estate, insurance, business service, educational service, health and social service, accommodation and food services, amusement and recreational services, personal and household service, other services.

[4] Other greenhouse gas emissions include carbon dioxide from non-combustion sources (industrial processes, agriculture and waste incineration), methane, nitrous oxide, and other gases. A major part of methane emissions and nitrous oxide emissions are caused by the biological decomposition of various waste streams and fertilizers, fugitive emissions from chemical processes, fossil fuel production, agriculture and many smaller sources. The focus of the present paper is on the greenhouse gases that result from energy consumption.

Figure 2. Trends in Energy Consumption by Fuel Type



2. Carbon Dioxide Emissions, Economic Growth and Productivity Performance

The previous section stressed the intimate connection between CO_2 emissions and energy consumption. The present section seeks to measure the extent to which the CO_2-to-energy consumption ratio $\frac{B}{E}$ (B stands for bad output, CO_2 emissions in our context), along with the energy intensity of output $\frac{E}{Y}$ (E, Y represent, respectively, real energy consumption and real gross output), contribute to the growth of the CO_2 emissions-to-output ratio $\frac{B}{Y}$ (see appendix).

The proposed framework suggests that the change in $\frac{B}{Y}$, the carbon intensity of output, can come about in various ways, which can be consolidated into two key elements, that is $\frac{B}{E}$ and $\frac{E}{Y}$. The latter may be further decomposed into two elements, energy per unit of all inputs $\frac{E}{Z}$ and the ratio of all inputs per unit of output $\frac{Z}{Y}$, or the inverse of multifactor productivity

$$\frac{B}{Y} = \frac{B}{E} \times \frac{E}{Z} \times \frac{Z}{Y} \cdot \quad (1)$$

The $\frac{B}{Y}$ ratio captures the relationship between CO_2 emissions and economic growth. It may also be used to ascertain the validity of the so-called ‘environmental Kuznets curve’ (EKC) at the industry level. The environmental Kuznets curve[5] hypothesis proposes that there is an inverted U-shape relation between various indicators of environmental degradation and income.[6] This has

[5] Kuznets (1955, 1963) actually examined the relationship between the degree of income inequality and the level of income.
[6] Grossman and Krueger (1995) is a pathbreaking study on the estimation of the EKC and its global implications.

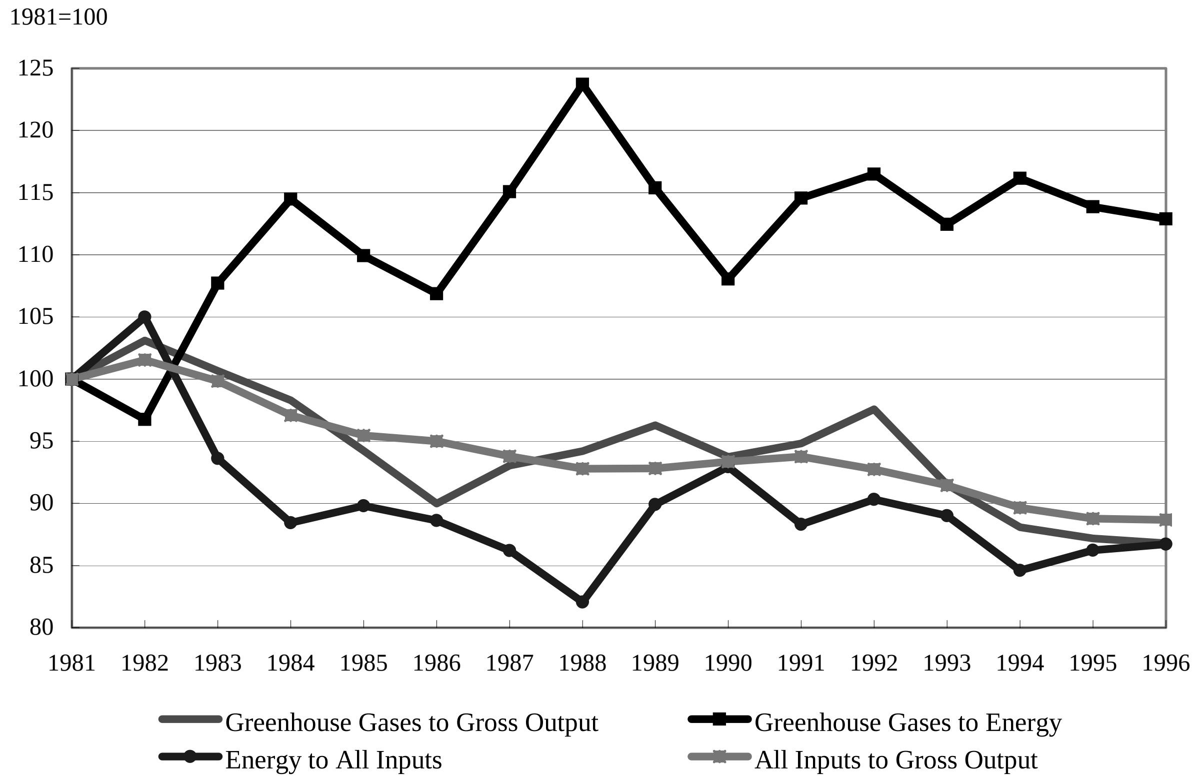
been taken to imply that economic growth may eventually redress the environmental impacts of the early stages of economic development and that growth will lead to further environmental improvements. Far from being a threat to the environment in the long-term, as argued in *The Limits to Growth* and *Beyond the Limits* by Meadows *et a*l. (1972, 1992) among others, economic growth is seen to be necessary in order for environmental quality to be maintained or improved. This is an essential part of the sustainable development argument as put forward in *Our Common Future* by WCED (1987). The EKC literature has examined empirical data to evaluate the latter argument.

The EKC theme was promoted by the World Bank's *World Development Report 1992* (IBRD 1992). The authors noted that: 'The view that greater economic activity inevitably hurts the environment is based on static assumptions about technology, tastes and environmental investments'(p. 38) and that 'As incomes rise, the demand for improvements in environmental quality will increase, as will the resources available for investment' (p. 39). Some have expounded this position even more forcefully: 'there is clear evidence that, although economic growth usually leads to environmental degradation in the early stages of the process, in the end the best—and probably the only—way to attain a decent environment in most countries is to become rich.' (Beckerman 1992)

Equation (1) suggests that the carbon intensity of output $\frac{B}{Y}$ can change either because of improved technology, because of shifts in the composition of output, or because of shifts in the input mix. It is important to separate these two latter effects.

Over the 1981-1996 period, the $\frac{B}{Y}$ ratio declined by 0.9 percent annually on average (energy and output are measured in constant prices) (Figure 3). The term $\frac{B}{E}$, which spotlights the effect of a changing mix of energy types consumed in terms of carbon emissions, increased over the same period by almost 0.81 percent on average. The second factor that may help explain the pattern of the $\frac{B}{Y}$ ratio is the energy intensity of output $\frac{E}{Y}$, an indicator of the extent to which business uses energy efficiently. One way in which economic growth *per se* may contribute to reduced emissions is through shifts in the composition of economic activity, for example, from natural resources to manufacturing and, subsequently, to services. Economic growth may also generate environmental benefits through the development and adoption of a new technology, which can result in improved energy efficiency and 'cleaner' methods of production. Over the same period, Canadian businesses recorded a drop of the energy to output ratio $\frac{E}{Y}$ of about 1.74 percent on average. This downward trend is the result of the decline in both the energy intensity of all inputs $\frac{E}{Z}$ (-0.95 percent) and the inputs intensity of output $\frac{Z}{Y}$, or the inverse of multifactor productivity (-0.80 percent).

Figure 3. Carbon Intensity of Output and its Sources of Growth



Note: Carbon intensity is the ratio of greenhouse gases to real output

IV. Multifactor Productivity Growth with a Bad Output

1. Framework

The conventional productivity framework that is used to measure the productivity performance of the business sector ignores an entire class of less desirable outputs, those that are a nuisance to society and therefore unmarketable. The result is an incomplete indicator of efficiency. This section provides an attempt to account for greenhouse gases in the standard multifactor productivity (MFP) framework defined as

$$\frac{\dot{Y}(t)}{Y(t)} - \left[s_K \frac{\dot{K}(t)}{K(t)} + s_L \frac{\dot{L}(t)}{L(t)} + s_E \frac{\dot{E}(t)}{E(t)} + s_M \frac{\dot{M}(t)}{M(t)} + s_S \frac{\dot{S}(t)}{S(t)} \right], \quad (2)$$

where $Y(t)$, $K(t)$, $L(t)$, $M(t)$, $E(t)$ and $S(t)$ represent output, capital, labour, material, energy and services inputs, respectively. The symbol « $\cdot$ » over each variable represents rates of change with respect to time. In other words, the rate of productivity change is defined as the difference between the growth rate of the output index and the growth rate of the input index. In turn, the input index is derived by weighting each factor of production by the proportional change in output that results from a small change in that input alone (technically, the output elasticity).

These weights are denoted by $s_i \ (i = K, L, E, M, S)$. If there is perfect competition in both the input factor markets and the output markets and there are constant returns to scale, these weights are equal to the shares of the individual factors in total costs and, consequently, add up to one.

The conventional methodology used to derive the multifactor productivity index can be extended in a straightforward way to take account of environmental damage from greenhouse gases. Emissions are joint outputs of the industrial process and can be included in the output index with weights determined by their marginal costs.

Environmental residuals can be incorporated into the framework by defining total output, Q, as the aggregation of marketed output, Y, and emissions, B. Total output exhibits a rate of growth equal to:

$$\frac{\dot{Q}(t)}{Q(t)} = s_Y \frac{\dot{Y}(t)}{Y(t)} + s_B \frac{\dot{B}(t)}{B(t)}. \tag{3}$$

According to this formula, the rate of change of total output is equal to a weighted average of the growth of output and the growth of emissions. The weights are equal to the shares of output and emissions in the total value of output. Of course, since emissions are damaging, they have a negative value rather than a benefit and so are expected to have negative shadow prices. Qualitatively, their impact on productivity is the same as that of input costs.

If MFP' is defined as the productivity index for the joint output function, Q, then the growth rate of MFP' is:

$$\begin{aligned} & s_Y \frac{\dot{Y}(t)}{Y(t)} + s_B \frac{\dot{B}(t)}{B(t)} \\ & -\left[s_K \frac{\dot{K}(t)}{K(t)} + s_L \frac{\dot{L}(t)}{L(t)} + s_E \frac{\dot{E}(t)}{E(t)} + s_M \frac{\dot{M}(t)}{M(t)} + s_S \frac{\dot{S}(t)}{S(t)} \right]. \end{aligned} \tag{4}$$

Comparing (2) with (4) gives:

$$MFP + s_B \left[\frac{\dot{B}(t)}{B(t)} - \frac{\dot{Y}(t)}{Y(t)} \right] \tag{5}$$

where:
$s_B =$ the weight of emissions in total output;
$\dot{B} =$ the change in emissions;
$B =$ the level of emissions;
$\dot{Y} =$ the change in the marketed output;
$Y =$ the level of marketed output.

Equation (5) resembles the total resource productivity measure proposed by Gollop and Swinand (2001). Their proposed measure equals the growth of marketable output in an industry, less the cost-share weighted growth of inputs (capital, labour and materials), plus the weighted growth in the product's environmental quality. Similarly, our framework shows how the conventional productivity measure (2) and the proposed measured adjusted for environmental effects (5) are related. Because s_B is negative, whenever emissions grow more slowly than output, the new productivity index will increase more rapidly than the conventional index. Furthermore, if output increases or stays constant, any decline in emissions will lead to a faster rate of productivity growth than that measured by the conventional index. Should emissions increase more rapidly than marketed outputs, however, the conventional index will overstate the productivity growth rate.

This revised methodology takes into account a potential source of productivity growth that the conventional methodology misses: a more rapid growth in the value of total output due to a shift toward highly valued marketable products and away from negatively valued waste products. This is as valid and potentially important an efficiency gain as any other. In some industries, as the next sections demonstrate, it has been an important source of improvement in productivity performance.

2. Measurement Issues

Calculating the new productivity measure requires an estimate of s_B, the share of emissions in total gross output. To obtain this share, we need to estimate the implicit price of emissions. This is estimated here as the derivative of the total private cost of production with respect to emissions. The following specification of the cost function has been estimated : $G(Y,B,w,D,t)$ is a private total cost function, where Y is the output; B is the "bad" output or emissions; w is a vector of input prices (labour, L; capital, K; energy, E; materials and services, M); D is a vector of dummy variables corresponding to fixed effects for each industry; and t is a time trend. In order to be consistent with the conventional productivity framework, the assumption of constant returns to scale was imposed on the estimation procedure.[7]

The variable B is included in the cost function because pollutants (bad outputs) are produced jointly with Y, or, conversely, because the environment is used as an input by producers when they release emissions into the atmosphere. Production of the bad output allows more marketable or good outputs Y to be produced from a given combination of paid inputs, or, alternatively, using emissions as an input allows the production of a given amount of Y at lower paid input costs.

The associated private shadow values s_B of the bad output, i.e. the (input) cost saving from allowing emissions, may be measured as the cost effects $\frac{\partial \ell n TC}{\partial \ell n B} = s_B$ (TC refers to the total private production cost). These shadow values of greenhouse gases, measured as the cost effects

[7] In a related paper (see Harchaoui and Lasserre, 2002), this assumption was not imposed and the impact on the productivity estimates after accounting for greenhouse gases was slightly higher (21% as opposed to the 17% reported here).

$\frac{\partial \ell nTC}{\partial \ell nB} = s_B$, reflect the marginal amount the producer incurs as it reduces B. We expect that $s_B < 0$. In our framework, s_B should thus be interpreted as the *private* value to producers, since it represents the amount that expenditure on other inputs would have to increase (at a given output level) if environmental emissions are to be reduced.

Measuring the shadow values of greenhouse gases and their link to the demand for other inputs and other components of the production structure was based on the estimation of a translog specification of $G(Y, B, w, D, t)$. This estimation is performed using a rich industry-level panel data set from Statistics Canada's productivity and environment programs with a multi-input and multi-output base. The dataset, based on 37 industries for the period 1981-1996, covers the primary sector, the manufacturing sector, the non-financial services sector and utility industries. We also derived the estimates for these sectors taken together by aggregating data across industries using industries output shares to reflect the industry composition and its change over time. We found the shadow values of greenhouse gases to be significant and larger for mineral industries and industries known as energy intensive.

3. Results

The results, reported in Table 1, show that taking into account pollutants (at least CO_2 emissions) is important. The adjustment factor, $s_B\left[\frac{\dot{B}(t)}{B(t)} - \frac{\dot{Y}(t)}{Y(t)}\right]$ is non trivial. This adjustment comprises a price and quantity effect, which may or may not have the same direction. The price effect s_B is expected to be negative. The estimates for four of the 5 major sectors considered in this study (primary, manufacturing, transportation, utility and other industries), accounting for the bulk of greenhouse gases, display the expected negative implicit price (s_B) of greenhouse gases—albeit not significant for transportation and manufacturing sectors. The utility sector, another major producer of greenhouse gases, is the only one that shows a positive and significant implicit price.[8] The estimate of the implicit price for the business sector of -0.14, as a weighted average of the individual sectors, is also statistically significant (at a five percent level). The primary sector shows the highest value (in absolute terms) of the implicit price (-0.89 significant at less than the 1 percent level), followed far behind by a group of other industries composed of construction, trade industries, communication and storage (-0.03 significant at 5 percent).

The quantity effect $\left[\frac{\dot{B}(t)}{B(t)} - \frac{\dot{Y}(t)}{Y(t)}\right]$, measured by the gap in terms of the average annual growth rate between the bad and the good outputs over the 1981-1996 period, could be either positive or negative. A negative value indicates that pollutant growth has been slower than output growth—that the efficiency of the industrial system has been improving. The gap of -0.98 percentage points shown by the business sector is mainly attributable to the manufacturing sector (-2.98 percentage points), followed by other industries (-1.06 percentage points) and utilities (-0.56

[8] This aberration is probably due to the regulated nature of the utility sector, a feature that our present cost function does take into account. However, the exclusion of utility sector from our data set does not alter our aggregate estimates of productivity in any significant way.

percent). In contrast, transportation and primary sectors are the only ones that display a positive quantity effect (respectively, 1.07 and .09 percentage points).

Table1: Productivity Performance with and without Bad Output, 1981-1996

	$\dot{Y}$	s_Y	t-statistic for s_Y	$\dot{B}$	s_B	t-statistic for s_B	MFP	MFP'
Primary	2.61	1.13	7.70	2.70	-0.89	3.44	1.60	1.52
Manufacturing	3.22	0.99	16.01	0.23	-0.03	1.39	0.68	0.78
Transportation	2.75	0.97	7.89	3.82	-0.03	0.73	1.13	1.10
Utility	2.66	0.94	9.15	2.10	0.17	5.32	0.11	0.01
Other	2.71	1.06	21.77	1.70	-0.03	1.93	0.55	0.57
Business Sector	2.95	1.03	16.01	1.98	-0.14	2.80	0.77	0.90

Notes: $\dot{Y}$ = average annual growth rate of the good output; $\dot{B}$ = average annual growth rate of the CO_2 emissions (the bad output); s_Y and s_B represent, respectively, the implicit prices of the good and bad outputs derived from the estimation of a long-run cost function; MFP =conventional multifactor productivity growth rate (based on only the good output); MFP' =alternative multifactor productivity growth rate (based on the good and bad outputs). These sectoral figures are obtained from the aggregation of 37 industry estimates using the chain Fisher index where the weights are defined in terms of nominal gross output.

The combination of negative price and quantity effects for a sector produces a positive effect on measured productivity growth. This is particularly the case for manufacturing (and to a lesser extent for other industries), where the average annual growth rate of multifactor productivity over the 1981-1996 period is now .78 percent, compared to .68 percent under the conventional framework—an increase of 15%. In other instances, where the quantity effect is positive, like for primary industries, the average productivity growth declined—1.52 percent, down from 1.60 percent without emissions. Overall, however, our results indicate that failing to account for emissions underestimates the productivity performance of the business sector by 0.13 percentage points over the 1981-1996 period—a difference of 17 percent.

Although based on a different approach applied to a different environmental problem, our conclusion is similar to the one reached by Gollop and Swinand (2001). Their results show that total resource productivity has grown faster than the conventional total factor productivity over all periods, except the 1972-79 period. In Gollop and Swinand (2001), the rapid growth of total resource productivity is due to the decline in water pollution from pesticide use since 1979. This is somewhat similar to our finding on the negative growth rate gap between the bad and good outputs.

V. Concluding Remarks

This paper has shown that pollutants can be reflected in the productivity performance indicator with only minor changes to the standard productivity framework. But before this is done, several obstacles need to be overcome.

The first challenge is one of obtaining acceptable, reliable implicit prices that can be attached to emissions. Waste products emitted to the environment, unlike saleable outputs, are not exchanged in markets and, therefore, do not have market prices. As Schelling (1992) remarked, 'The worst things in life are free.'

Undeniably, the fact that emissions lack market prices makes estimating their incremental cost to the economy difficult. But as we have shown here, it is not impossible. Nevertheless, it must be recognized that the estimates reported here are just that—estimates. They are derived from the specification of a cost function that rarely captures all of the complexity of the industrial process. The validity of the estimates also depends upon other factors, such as the reliability of the statistical techniques used and the accuracy of the data employed. While we have employed the best data available and statistical techniques that are state-of-the-art, we recognize that we are not at the point where we can definitively say that the estimated shadow prices are as accurate as we would like.

The second challenge behind the construction of more comprehensive productivity accounts is the development of a comprehensive database on pollutants using the Input-Output tables framework. Preparing and maintaining a revised record of productivity growth requires an adequate information base. Statistics Canada has made great strides in developing environmental databases, using them for economic analysis and making them publicly available. This paper is a first step in using an experimental methodology to account for the impact of greenhouse gases on productivity growth. As a by-product, it also produces the shadow price of greenhouse gases, a measure of the private cost businesses have incurred as they have reduced CO_2 emissions. Credible estimates of implicit environmental prices may be useful not only for productivity measurement, but also for priority setting in environmental policy, regulatory analysis, and other purposes.

Individual companies are keenly interested in their own productivity records, and, companies in environmentally sensitive industries are searching for performance metrics and indicators that can adequately reflect their individual progress toward 'eco-efficiency'. The methodology outlined here can readily be adapted for this purpose. It measures efficiency gains in the use of conventional inputs—capital and labour as well as raw materials and intermediate inputs. In addition, it measures progress in reducing emissions and effluents. Estimates of damage costs would have to be particularized to each company's own sites and the composition of its waste streams. This would provide environmental managers with information useful in priority setting. Environmentally progressive companies, that begin tracking their own productivity improvements using this basic methodology, will be better able to integrate their environmental- and business-management practices.

Appendix

Output per Unit of Greenhouse Gases, Average Annual Growth Rate (Percentage)

	1981-1996	1981-1988	1988-1996
Agricultural and related service	3.2	-0.9	6.9
Fishing and trapping	1.7	5.2	-1.3
Logging and forestry	0.3	2.8	-1.9
Mining	2.3	4.1	0.7
Crude petroleum and natural gas	-0.5	-3.3	2.1
Quarry and sand pit	2.0	8.9	-3.6
Services incidental to mineral extraction	6.0	3.8	8.0
Food	1.0	0.7	1.3
Beverage	4.0	5.6	2.7
Tobacco products	1.3	0.7	1.8
Rubber products	6.2	3.0	9.1
Plastic products	3.2	1.0	5.1
Leather and allied products	0.6	-1.2	2.1
Primary textile	4.7	7.8	2.1
Textile products	-1.0	-5.6	3.3
Clothing	3.7	-2.4	9.4
Wood	0.9	5.0	-2.6
Furniture and fixture	0.1	-3.4	3.3
Paper and allied products	2.7	7.6	-1.4
Printing, publishing and allied	-2.1	-4.6	0.2
Primary metal	2.8	2.7	2.9
Fabricated metal products	-0.4	-2.5	1.5
Machinery (except electrical mach)	1.8	-1.9	5.1
Transportation equipment	4.3	2.7	5.7
Electrical and electronic products	11.7	8.1	14.9
Non-metallic mineral products	-0.2	2.0	-2.0
Refined petroleum and coal products	-1.4	-1.9	-1.0
Chemical and chemical products	2.0	1.4	2.5
Other manufacturing	2.7	-2.3	7.3
Construction	1.0	4.8	-2.2
Transportation	-0.0	0.9	-0.8
Pipeline transport	-1.8	-1.4	-2.2
Storage and warehousing	2.9	-4.1	9.5
Communication	-0.7	5.6	-5.9
Other utility	0.6	-0.9	1.8
Wholesale trade	2.1	7.7	-2.7
Retail trade	1.6	4.9	-1.2
Finance and real estate	0.8	-0.3	1.8
Insurance	4.8	10.2	0.3
Business service	5.0	2.6	7.1
Educational service	2.7	-3.3	8.3
Health and social service	3.4	3.7	3.1
Accommodation and food services	5.2	5.0	5.5
Amusement and recreational service	-2.2	3.5	-7.0
Personal and household service	5.1	5.0	5.1
Other service	0.4	1.7	-0.8
Business Sector (Weighted Average)	1.9	2.3	2.0

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