The Measurement of the Energy Intensity of Manufacturing Industries: A Principal Components Analysis

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Abstract

Energy intensity is the ratio of energy use to output. Most industries deal with several energy sources and outputs. This leads to the usual difficulties of aggregating heterogeneous inputs and outputs. We apply principal components analysis to assess the information derived from six energy intensity indicators. We use two measures of total energy use (thermal and economic) and three measures of industry output (value added, value of production, and value of shipments). The data comes from manufacturing industries in Québec, Ontario, Alberta, and British Columbia from 1976 to 1996. We find that the variation of the six energy intensity indicators that is accounted for by the first principal component is quite large. However, depending on how variables are measured, there may be significant differences in the assessment of the evolution of inergy intensity for some industries. There are no particular patterns in this respect. This makes identifying benchmarks that could be used to assess future performance difficult.

Key Words: Energy intensity; aggregation; principal components analysis

JEL Classification Numbers: Q40, C43, L60

Contents

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Introduction

Most governments pay close attention to the energy demand of their countries. The governments' interest in this particular case follows from concerns about the stable growth of the national economy, the economy's capacity to meet the challenges presented by international competition, and the protection of the environment. As a result, governments regularly publish analyses of the evolution of energy demand by sector and for the whole economy.[1] Particular attention is paid to energy intensity, which is the ratio of energy use divided by output. This simple ratio provides an indicator of the efficiency of energy use.[2]

Energy intensity is best understood as a productivity indicator, and its interpretation does not give rise to difficulties in simple instances such as litres of gasoline per kilometer or kilowatt-hours of electricity per ton of aluminum. However, most applications deal with more complex cases, which involve several energy sources and several products. In these circumstances, we face the familiar aggregation problem related to adding together heterogeneous goods.

Two approaches coexist with respect to the measurement of aggregate energy use. In the first approach, which is chosen by most public agencies, the energy sources are added together on the basis of their thermal content such as joules, British thermal units, or tons of oil equivalent. The second approach has roots in the economic tradition of

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[1] See *Energy Policy*, special issue, June/July, 1997, and International Energy Agency (1997). For Canada, see Natural Resources Canada, Office of Energy Efficiency (2000), (2001).

[2] For a discussion on the various concepts related to the measure of energy efficiency, see Patterson (1996).

relying on prices as aggregation factors.[3] Several authors have examined the effects that follow when these two approaches are applied in particular cases.[4] The presentation of the results is usually descriptive, and no coherent analytical framework is applied to evaluate the extent to which the information embodied in the energy efficiency indicators is or is not common to them.

The purpose of this paper is to gather such information through the application of principal components analysis. This statistical method allows us to transform one set of variables into another set of orthogonal variables that shed some light on the characteristics of the original data. In this particular case, important characteristics of the original data are potentially linked to the manner in which various variables are measured.

Our sample deals with the energy use of 18 manufacturing industries in four Canadian provinces—Québec, Ontario, Alberta, and British Columbia (B.C.)—from 1976 to 1996. We build two measures of total energy use for each industry, one that relies on the thermal content (joules) of each energy source, and the other that is based on prices.[5] Three measures of aggregate industrial output are available: value added, value of shipments, and value of production. This allows us to construct six indicators of energy intensity for each industry over the sample period. Through principal components analysis, we assess the information on energy intensty that is common to the six energy intensity indicators as revealed by the relative size of the first characteristic root. The first characteristic vector is an aggregate of the six energy intensity indicators and it can be interpreted as a generalized measure of energy intensity. In some cases, other characteristic vectors and their associated roots shed some light on the role played by the measurement of energy use and manufacturing output.

The original data have been collected by Statistics Canada through the annual census of manufacturing. The fact that the data have been gathered by the same statistical agency allows us to avoid some problems that may appear in studies that rely on international data, such as definition of industry, coverage of energy sources, and sampling methods. Even if the statistical information relates only to the Canadian

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[3] This is how gross national product is measured.

[4] See Turvey and Nobay (1965), Hong (1983), Bernard and Cauchon (1987), and Zarnikau (1999).

[5] More explicitely we use the Theil quantity index, which will be defined in section 1.

economy, the evolution of the manufacturing industries within the four provinces over the sample period provides a fairly rich mix in terms of industrial composition and energy use.[6]

Practical considerations guided us in the choice of the sample period. The part of the Canadian annual census of manufacturing that deals with energy use was fairly stable during these years while major changes were occurring in the energy markets. The first few years were marked by the aftermath of the oil crises of 1973 and 1979, when oil prices skyrocketed. This period was followed by the oil and natural gas price deregulation in 1985. Thereafter, the oil prices fell quickly and stayed more or less stable until 1996.[7]

Here is the order of presentation. In section 1, we show why the thermal and the economic measures of total energy use behave differently if consumers are minimizing energy costs while energy prices are changing. In section 2, we briefly discuss the relationships between value added, value of shipments, and value of production as measures of aggregate industry output. Section 3 shows some information on the manufacturing industries of the four provinces. Section 4 presents the results of the principal components analysis of the six measures of energy intensity for each of the manufacturing industries of the four Canadian provinces. We conclude with some comments on the relevance of our findings for policy initiatives to limit greenhouse gas emissions.

Here are the main conclusions that we draw from the application of principal components analysis to the six energy intensity indicators. There are obvious divergences among the annual growth rates of the six energy intensity indicators for each industry. However, if we use 90% or more as a benchmark for the relative size of the characteristic root of the first principal component, which may be interpreted as an aggregate measure of energy intensity derived from the six energy intensity indicators, the criterion is satisfied by 13 out of 16 manufacturing industries in Québec, 17 out of 17 in Ontario, 9 out of 15 in Alberta, and 10 out of 16 in B.C. So the share of the total variation of the six energy intensity indicators which is represented by this aggregate measure is quite significant. However, other characteristic vectors and the associated characteristic roots reveal that the thermal measurement of aggregate energy use rather than the economic

[6] This point will be developed further in section 3.

[7] Except for a few weeks in the fall of 1990, when Iraq invaded Kuwait.

measurement, as well as the use of value added rather than value of shipments or value of production, create significant differences in energy intensity indicators for some manufacturing industries. Unfortunately, there is no explicit pattern in this respect.

1. The Measure of Aggregate Energy Use

The aggregation problem arises when more than one energy source are used. Most public agencies use thermal factors associated with each energy source to arrive at total energy use:

$$E_t^{Ther} = \sum_i^N J_i E_{it} \qquad (1)$$

where : E_t^{Ther} = total quantity of energy expressed in thermal units (joules) for period t:

J_i = number of thermal units (joules) associated with energy source i;

E_{it} = quantity of energy source i used during period t;

N = number of energy sources.

The thermal factors J_i represent how much heat can be produced from energy source i under specific laboratory conditions.[8] Actual use may not display the same efficiency in obtaining heat from energy source i. The main defect of expression (1) as an aggregation formula is that all energy sources are considered to be substitutable on the basis of their thermal contents. If this were the case, market competition would lead to the equality of the energy prices in terms of their thermal contents. We do not observe such equality in the real world: joules associated with electricity are more expensive than joules associated with oil products, which are more expensive than joules from coal. There is a simple reason for the price differences: considerations other than heat content enter into the decision to purchase a particular energy source.

[8] In the application that follows, the thermal output of natural gas is subject to some minor changes from year to year.

Economists guided by basic economic principles favor the use of market prices as the proper way to measure the exchange rate between goods. This is the reminder that was expressed by Turvey and Nobay (1965) with respect to the measure of aggregate energy consumption. To appreciate the differences that could arise when the thermal measure of total energy in (1) is used rather than a formula that embodies the economic principles, let us consider a situation where the price of oil products goes up relative to the price of electricity. Consumers looking to minimize costs would prefer using less oil and more electricity. If the marginal rate of substitution is decreasing, this would be registered by formula (1) as a decrease in total energy use, since oil has a higher heat content than economic value relative to electricity.[9] This bias is not present in an economic aggregation formula that gives more weight to electricity, which has a higher market value per unit of heat.

There exist several quantity indices that use prices as weighting factors.[10] In this paper, we use the Theil quantity index that is defined as follows:[11]

$$I_t^{THEIL} / I_{t-1}^{THEIL} = \prod_i^n (E_{it} / E_{it-1})^{\tilde{w}_{it}} \qquad (2)$$

where: I_t^{THEIL} = Theil quantity index at period t;

$\tilde{w}_{it}$ = relative weight of energy source i at period t;

$$= \left[\frac{1}{2}(w_{it} + w_{it-1})\, w_{it} w_{it-1}\right]^{1/3} \Bigg/ \sum_i^N \left[\frac{1}{2}(w_{it} + w_{it-1})\, w_{it} w_{it-1}\right]^{1/3}$$

w_{it} = expenditure share of energy source i at period t;

$$= p_{it}\, E_{it} \Bigg/ \sum_i^N p_{it}\, E_{it}$$

where: p_{it} = price of energy source i at period t.

[9] For a graphic presentation of this proposition, see Bernard and Cauchon (1987).

[10] Let us mention the most common ones: Laspeyres, Paasche and Fisher.

[11] Theil (1973).

The Theil quantity index is a member of the set of Divisia indices that are known to have desirable features.[12] The main advantage of the Theil formula is that it allows for the coherent introduction or withdrawal of energy sources over time. This phenomenon occurs regularly in our sample. As a closing comment to this section, let us mention that the size of the divergence between the thermal and the economic measures of aggregate energy use is an empirical question.

2. The Measure of Manufacturing Output

The energy intensity indicator is the ratio of output to energy used. In this study, output is the set of products provided by a manufacturing industry as defined under the standard industrial classification (SIC), which was adopted by Statistics Canada. At this fairly high level of aggregation, measurements of manufacturing industry outputs in physical units are meaningless and we must use the readily available economic measures of industry outputs that are published by Statistics Canada. We have access to three measures of output: value of production, value of shipments, and value added. Here are the relationships that exist among these three measures:[13]

VP_t = value of production in constant \$ at period *t*.

VS_t = value of shipments in constant \$ at period *t*.

$$= VP_t - \Delta INV_t \quad (3)$$

where: ΔINV_t = change in the value of inventories in constant \$ at period *t*.

VA_t = value added in constant \$ at period *t*.

$$= VP_t - CI_t \quad (4)$$

where: CI_t = costs of intermediate inputs (energy and materials) in constant \$ at period *t*.

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[12] See Diewert (2001).

[13] We follow the presentation in Freeman et al. (1997)

As can be observed from (3) and (4), value of production is a component of value of shipments and of value added, hence we expect that pairwise correlations of the three variables are high. However, change in the value of inventories (ΔINV_t) is taken out of value of production to arrive at value of shipments, while costs of intermediate inputs (CI_t) are subtracted from the same variable to arrive at value added. The three variables VP_t, ΔINV_t, and CI_t follow different paths over business cycles and there is no perfect correlation among the three measures of manufacturing output.

Let us look more closely at the variables that enter into the measure of the value of production in constant dollars:

$$VP_t = (Q_t \bullet P_t) / PI_t \qquad (5)$$

where: Q_t = the vector of products manufactured by an industry at period t;

P_t = the vector of market prices associated with Q_t at period t;

PI_t = the price index for industry output at period t.

VP_t is a one-dimension variable that depends on multidimensional vectors P_t and Q_t and on the way P_t enters into the price index PI_t. So VP_t is not a perfect mirror of Q_t unless all the quantities of the products change at the same rate. We must recall the simple fact that some information is lost through aggregation and as a result there are no perfect aggregation formulas.

Freeman et al. (1997) analyzed the relationships that existed between the three economic measures of manufacturing output and physical units for 14 industries for which it was possible to measure output in physical units. The relationships among the variables were assessed on the base of three statistical criteria: coefficient of variation, simple correlation, and growth trend. Their main conclusion is that no single economic measure of output displays a closer relationship to physical output for the 14 industries than the other two. So Freeman et al.'s study does not guide us in the choice of the appropriate economic measure of manufacturing output. In section four, we will assess whether the use of one or the other economic measures of manufacturing output significantly influence the measurement of energy intensity for the manufacturing industries of four Canadian provinces between 1976 and 1996.

3. Manufacturing industries output and energy use from 1976 to 1996

Before we proceed with the analysis of the energy intensity indicators, it is appropriate to have in mind the salient features of the manufacturing industries that are part of the sample.[14]

Table 1 provides some information on the absolute and relative size of each manufacturing industry and their growth rates during the sample period. Size is based on a 21-year average. It can be seen that the Ontario total manufacturing sector is about twice the size of the Québec one; B.C. and Alberta have much smaller manufacturing sectors.

If we look at the shares of the industries across the four provinces, we can observe that some provinces specialize in certain industries. If we take a 4% or more differential between the largest and the smallest shares across the provinces as an indicator of specialization,[15] we observe specialization in food and beverage (Alberta), textile and clothing (Québec), wood (B.C. and Alberta), paper and allied products (B.C. and Québec), transportation equipment (Ontario and Québec), electrical products (Ontario), and chemical products (Alberta).

The last row for each province shows the annualized growth rate of the manufacturing industries during the sample period. Alberta's total manufacturing sector grew at the astounding annual rate of 4.6%; then Québec and Ontario follow at 1.9%, and finally B.C. has the smallest growth at 0.9%.

The experience of the industries within each province is quite diverse during this particular period. Major changes came out of the Free Trade Agreement (FTA) with the United States in 1989 and the North American Free Trade Agreement (NAFTA) that included Mexico in 1994. In Québec, food and beverage, leather, textile, clothing, furniture, paper, printing, metal fabricating, nonmetallic mineral products, and petroleum

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[14] See the Data Appendix for the presentation of data sources.

[15] The 4% criterion is arbitrary and is used only for descriptive purpose.

and coal products grew at a slower pace than the total manufacturing sector. The same changes took place in Ontario with the exception of clothing, which had a higher growth rate, and primary metals and machinery, which had lower growth rates. In Alberta, food and beverage, clothing, furniture, printing, primary metal, metal fabricating, transportation equipment, and nonmetallic mineral products experienced less growth than the provincial total manufacturing sector. In B.C., wood, paper, primary metal, transportation equipment, and petroleum and coal products were the slow growth sectors relative to the province average.

Table 2 shows the share of energy costs relative to value of production, and the leading energy source and its share of energy costs for each manufacturing industry. The numbers represent averages during the sample period. Energy costs account for more than 3.0% of value of production only in four industries: paper and allied products, primary metal with the exception of B.C., nonmetallic mineral products, and chemical and chemical products. They are the so-called energy intensive industries. Except for Alberta, electricity is the leading energy source in total manufacturing sector in terms of its share of energy costs. This is based on the fact that electricity has the largest share of energy costs among most industries with few exceptions where natural gas moves ahead of electricity. Here are the exceptions to electricity predominance: primary metal (Alberta and B.C.), nonmetallic mineral products (Alberta, B.C. and Québec), petroleum and coal products (all provinces), and chemical and chemical products industries (Alberta).

Table 3 displays the information on the evolution of the real price of energy by sources and in total as measured by the Theil price index for the total manufacturing sector.[16] It can be seen that energy prices went through similar changes in Québec, Ontario, and B.C. However, energy price changes were very different in Alberta: the real price of coal increased, the real price of natural gas did not fall to the same extent and, finally, the prices of oil products and electricity increased at a lower rate. Overall, the real price of energy increased in all provinces although the increase was less in Alberta.

The data presented in this section shows that the evolution of the manufacturing industries in the four provinces was quite diverse from 1976 to 1996, and that it provides a natural experiment to assess the extent to which some commonly used energy intensity indicators embody the same information.

[16] Relative to the price of the output.

4. Energy intensity indicators and principal component analysis

Let us recall briefly the gist of principal components analysis.[17] This is a statistical method that transforms one set of original variables into another set of the same dimension. The transformed variables are the so-called principal components and they have two properties that will be used extensively later on: the first property is the linear transformation of the original variables. The linear coefficients represent the weights that are allocated to each original variable in the formation of the principal components and they provide useful information on the role played by the original variables. The second property is the orthogonality of the principal components. This allows the total variation that is embodied in the set of original variables to be decomposed into the product of factors, which are the variances of the principal components. Hence the relative variances of the principal component tell us how much of the variation that is present in the original variables is captured by each principal component.

This is why the principal components method is usually described as a method that can be used to shrink a set of variables into another set of variables that has a smaller dimension and encompasses most of the variation that appears in the original set. The linear coefficients can be used to give an interpretation, if possible, of the transformed variables that are the principal components. We use principal components analysis not so much to reduce the size of a set of variables, but rather as a tool to analyze the information included in the six measures of energy intensity that come from the two measures of energy use and the three economic measures of industry outputs.

The first principal component is an aggregate of the six energy intensity indicators and the relative size of the first characteristic root, which is its variance, tells us how much of the total variation of the six energy intensity indicators is captured by this aggregate. The relative size of the other characteristic roots, which are the variances of the other principal components, guide us in the search for significant features of the original data that contribute to differences between the six energy intensity indicators. In particular, we want to see if the measurement of the variables play a significant role.

Before we turn to the results of the principal components analysis as such, let us see briefly how the six indicators of energy intensity of the manufacturing industries have

[17] For an elementary introduction to principal components analysis, see Dunterman (1989). Morrison (1976) provides a summary of the main statistical properties.

evolved during the sample period. This will allow us to appreciate the extent of their similarities or their differences within each industry. Tables 4 to 7 show the annualized growth rate of the six indicators of energy intensity by province. If we look at total manufacturing only, Ontario (Table 5) shows the largest decline in energy use per unit of output and it is followed by B.C. (Table 7). The data show little changes in Québec (Table 4) while energy use per unit of output increased in Alberta (Table 6), although in that province one energy intensity indicator—joules per value added—shows an improvement. If we had used only joules per value added as the energy intensity indicator, we would have come to the conclusion that B.C. and Alberta had more or less the same performance. It is worth pointing out that even though all six indicators vary in the same direction in Ontario, the extent of their difference is quite substantial: joules per value of shipments show the largest decrease (–3.0%), while Theil quantity index per value added displays a smaller decrease at -2.01%. The gap between the two annual growth rates is 1.0% and is quite significant over a 21-year period.

The last column in Tables 4 to 7 shows the direction of the changes of the energy intensity indicators for each industry. The six energy intensity indicators display changes in the same direction with few exceptions: one in Québec, one in Ontario, two in Alberta, and none in B.C. This is limited to the direction of changes; however there are large gaps between the rates of change in numerous instances, even though the six energy indicators move in the same direction. We make use of principal component analysis, which provides a coherent framework to sort out what is common and what is different in these six energy intensity indicators.[18]

Table 8 shows the coefficients of the characteristic vectors, their interpretation when an interpretation is deemed to be appropriate, and the relative size of the associated characteristic roots for the total manufacturing sector of each province. The coefficients of the first characteristic vector are all positive and are fairly close in size, so we interpret the first principal component as an aggregate which is a generalized measure of energy intensity. The relative size of the associated characteristic root is larger than 85% in all provinces and reaches 99.45% in Ontario. This shows that a large share of the variation in the original data comes from the common changes of the energy intensity indicators. The

[18] The conclusions that are drawn from principal components analysis are not independent of the unit used to measure the original variables. This is not a problem in this application, since we are interested in the evolution of energy intensity indicators over a given period. All six indicators are scaled to 1.00 in 1976.

second characteristic vector in Québec represents a contrast[19] between the Theil quantity index and joules measure of energy use and the relative size of the associated characteristic root is 7.88%. This shows that using one or the other measure of total energy use accounts for 7.88% of the variation in the original variables. The third characteristic vector in Québec represents a contrast between value added on the one hand and value of production and value of shipments on the other. Of the variation in the original variables, 3.60% is accounted for by the latter contrast. The relative size of the three other characteristic roots is rather small and hence the information that can be derived from them is close to nil. In Ontario, almost all the variation in the original variables is captured by the first principal component and there is no other significant characteristic root. In Alberta, the second largest relative characteristic root is associated with a vector that represents a contrast between value of production and value of shipments on the one hand and value added on the other. The measures of manufacturing output turn out to play a significant role in this case. The third characteristic vector, which has a fairly small relative characteristic root (1.97%), represents a contrast between the two measures of total energy use. The pattern of characteristic vectors and their associated characteristic roots in B.C. is similar to what is observed in Alberta.

Table 9 presents the results for all the manufacturing industries with respect to the relative size of the characteristic roots and the interpretation of the associated characteristic vector (when such an interpretation is appropriate). With only two exceptions, the relative size of the first characteristic root is larger than 80.0%. This indicates that the total variation of the six energy intensity,indicators, which is captured by the first characteristic vector, is fairly large. The two exceptions are the petroleum and coal industries in Alberta and B.C. In these two cases, more than 30% of the total variation of the original variables comes from the use of value added on the one hand and value of production and value of shipments on the other as measures of industry output. We can see that in some cases the two measures of aggregate energy use and the three measures of aggregate industry output form a significant source of variation in the evolution of the energy intensity indicators. However, there appear to be few explicit patterns by industry in the four provinces.

[19] The characteristic vectors are normalized to have length equal to one and they are orthogonal to each other. The orthogonal condition implies that the coefficients of two characteristic vectors cannot have the same signs. This is why characteristic vectors are interpreted as contrasts in terms of the original variables.

Table 10 shows the annualized growth rate of the first principal component of all the industries in each province and the extent to which this information is common to all six original energy intensity indicators measured by the relative size of the first characteristic root. These growth rates stem from the weighted average of the six original energy intensity indicators and the weights are obtained from principal components analysis. The weights represent the contribution of each original variable to this aggregate measure of energy intensity by industry.

If we look at total manufacturing, Ontario (-2.37%) presents the best performance in reducing energy use per unit of output and is followed by B.C. (-0.51%), Québec (0.00%), and Alberta (0.16%). For the last three provinces, the information on energy intensity embodied in the aggregate is not as precise as in Ontario—the first characteristic vector represents less than 90% of the total variation included in the original six indicators of energy intensity, while it exceeds 99.0% in Ontario.

If we look at the results for the manufacturing industries, we see that there are large differences in the growth rates across provinces and that the level of precision of the aggregate as revealed by the relative size of the first characteristic root is also quite variable. If we focus the attention on the four most energy-intensive industries, here is what we observe: the energy intensity of paper and allied products has decreased in all four provinces except B.C.; the energy intensity of primary metal has decreased in all four provinces except Québec; the energy intensity of nonmetallic mineral products has decreased everywhere with the exception of Alberta, and, finally, the chemical and chemical products industries have reduced energy use per unit of output in all four provinces. Again there are large differences in the growth rates and in the precision of the aggregate measure of energy intensity as is revealed by the relative size of the first characteristic root.

Conclusion

Manufacturing industries make use of several energy sources and make several products available to consumers. This diversity creates aggregation problems for analysts who are interested in representing the evolution of energy intensity—which is the ratio of energy use to output—in the most meaningful way.

In this paper, we use principal components analysis to decompose the total variation embodied in six energy intensity indicators. The characteristic vectors and their associated characteristic roots allows us to measure the share of the total variation of the six energy indicators which is captured by an aggregate measure of energy intensity and to sort out the sources of some of their differences. These six energy intensity indicators are built from two measures of total energy use (thermal and price weights) and three measures of manufacturing industry output (value of production, value of shipments, and value added). The sample comes from the manufacturing industries of four Canadian provinces during the period from 1976 to 1996.

We find that the information that is common to the six energy intensity indicators, as revealed by the first characteristic vector and its relative characteristic root, is quite significant. However, in a few cases, either the two ways of measuring aggregate energy use or the three ways of measuring industry output are major sources of difference in measuring the evolution of energy intensity at the industry level. Unfortunately, there are very few explicit patterns in this respect.

Our empirical results have some relevance to energy policymakers who are devising ways to reduce energy consumption in order to decrease the emission of gases that contribute to global warming. Thus far, voluntary programs have received widespread support[20] and sometimes credits may be earned in this fashion. The historical record shows a very large array of outcomes in this regard during the sample period. There are significant differences between industries and also between provinces for the same industry. This makes it difficult to establish meaningful benchmarks that could be used to assess future performance or commitment, as it is introduced in the so-called output performance method of allocating green house gas emission permits.[21]

[20] This is a major aspect of the U.S. government policy on greenhouse gas that seeks to reduce greenhouse gas intensity of the U.S. economy by 18% by 2012. See the White House (February 2002).

[21] See Burtraw et al. (2001). This is one of the options that are considered by the Canadian government (2002) in the implementation of the Kyoto Protocol.

TABLE 1

Average value added (M$ 1992) - Average share of manufacturing sector (%) - Annualized growth rate (%) from 1976 to 1996

	Total manufacturing*	Food and beverage	Rubber and plastic products	Leather and allied products	Primary textiles and textile products**	Clothing***	Wood	Furniture and fixture	Paper and allied products	Printing, publishing	Primary metal	Fabricated metal products	Machinery	Transportation equipment	Electrical and electronic products	Non-metallic mineral products	Refined petroleum and coal	Chemical products	Other manufacturing
Québec	24 927.7	3 499.3	i.d.	226.4	1 062.1	1 644.8	1 051.6	612.8	1 920.9	1 938.1	1 489.6	1 608.8	853.9	2 091.9	1 321.6	662.5	166.7	1 648.8	i.d.
	100.0	14.0		0.9	4.3	6.6	4.2	2.5	7.7	7.8	6.0	6.5	3.4	8.4	5.3	2.7	0.7	6.6	
	1.9	0.0		-1.3	1.1	0.3	3.9	-0.2	1.8	0.1	4.1	0.2	2.6	5.7	7.0	-1.4	1.0	3.0	
Ontario	47 777.5	6 124.3	1 805.8	280.7	1 011.5	976.0	784.9	1 031.1	1 784.7	3 741.4	2 707.3	4 162.4	2 724.6	8 712.7	2 992.7	1 411.2	318.9	3 652.4	i.d.
	100.2	12.8	3.8	0.6	2.1	2.0	1.6	2.2	3.7	7.8	5.7	8.7	5.7	18.2	6.3	3.0	0.7	7.6	
	1.9	0.7	3.8	-9.9	0.5	2.3	3.0	1.3	1.6	0.6	0.6	0.7	1.2	4.0	5.5	-0.8	0.2	2.7	
Alberta	5 219.9	987.9	i.d.	i.d.	i.d.	66.7	297.6	93.2	206.8	457.0	193.8	446.6	349.7	108.6	152.0	333.3	136.3	861.0	95.9
	100.0	18.9				1.3	5.7	1.8	4.0	8.8	3.7	8.6	6.7	2.1	2.9	6.4	2.6	16.5	1.8
	4.6	1.8				-0.1	5.6	3.9	5.3	1.4	3.0	3.3	5.3	0.0	14.2	-0.3	6.8	10.2	5.5
B.C.	8 458.1	1 142.8	i.d.	i.d.	35.6	97.2	2 073.4	80.5	1 180.0	558.5	316.3	507.2	325.8	351.0	145.6	269.6	102.5	244.7	108.8
	100.0	13.5			0.4	1.1	24.5	1.0	14.0	6.6	3.7	6.0	3.9	4.2	1.7	3.2	1.2	2.9	1.3
	0.9	1.2			6.0	1.6	0.6	1.5	-2.0	1.2	-0.5	1.8	3.2	0.4	9.9	1.6	-1.3	1.8	5.0

i.d.: Incomplete data.

* Total manufacturing may exceed the sum of the industries since some industries are left out.

**Data from 1992 to 1996 are missing for B.C.

*** Data from 1976 to 1978 are missing for Alberta.

TABLE 2
Average share of energy costs in production value (%)
The leading energy source: It's share of energy costs (%)
from 1976 to 1996

	Total manufacturing	Food and beverage	Rubber and plastic products	Leather and allied products	Primary textiles and textile products*	Clothing**	Wood	Furniture and fixture	Paper and allied products	Printing, publishing	Primary metal	Fabricated metal products	Machinery	Transportation equipment	Electrical and electronic products	Non-metallic mineral products	Refined petroleum and coal	Chemical products	Other manufacturing
Québec	3.13	1.59	i.d.	0.84	2.69	0.62	2.80	2.80	9.50	0.71	8.03	1.58	1.22	0.94	0.95	8.76	1.81	3.99	i.d.
	E	E		E	E	E	E	E	E	E	E	E	E	E	E	G	G	E	
	57.9	39.7	i.d.	71.8	52.4	68.6	62.4	61.2	67.2	72.1	55.3	48.5	56.3	52.9	68.6	33.7	55.1	65.5	
Ontario	2.24	1.56	2.34	1.24	3.00	0.70	2.82	1.21	6.27	0.82	5.36	1.62	1.06	0.80	0.92	7.35	1.83	4.96	i.d.
	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	G	E	
	52.3	43.5	68.7	53.2	49.7	63.2	52.7	53.9	54.0	66.6	56.6	51.3	55.0	62.2	65.2	39.7	50.9	44.7	
Alberta	2.69	1.13	i.d.	i.d.	i.d.	0.80	2.67	1.10	4.33	0.89	3.97	1.34	1.14	1.15	0.54	5.99	1.63	7.94	0.96
	G	E				E	E	E	E	E	G	E	E	E	E	G	G	G	E
	54.1	47.7				63.3	50.8	60.3	54.9	73.5	50.5	54.3	52.3	53.1	77.8	47.8	61.6	70.2	68.4
B.C.	3.30	1.24	i.d.	i.d.	1.03	0.53	2.46	1.10	9.07	0.73	2.30	1.31	1.05	0.80	0.74	7.11	1.18	6.76	1.09
	E	E			E	E	E	E	E	E	G	E	E	E	E	G	G	E	E
	53.5	45.0			74.4	68.3	59.2	68.5	53.3	73.6	46.8	57.8	64.8	54.3	76.5	40.5	52.8	81.6	55.2

i.d.: incomplete data
* Data from 1992 to 1996 are missing for B.C.
** Data from 1976 to 1978 are missing for Alberta

E: electricity
G: natural gas

TABLE 3

Real price change of energy sources in total manufacturing from 1976 to 1996

(%)

Energy Source	Québec	Ontario	Alberta	British Columbia
Coal	-40.0	-51.0	29.6	-67.2
Natural gas	-16.6	-16.7	-7.0	-16.0
Electricity	43.6	50.6	14.5	55.5
Oil products	40.7	51.2	7.9	40.6
Theil price index	28.6	23.0	6.9	24.3

TABLE 4

Annualized growth rate of energy intensity indicators from 1976 to 1996 in Québec

(%)

	Theil quantity index divided by			*Joules divided by*			
	Production Value	***Shipments Value***	***Value Added***	***Production Value***	***Shipments Value***	***Value Added***	
Total manufacturing	0.17	0.15	0.07	-0.11	-0.14	-0.21	?
Food and beverage	-0.29	-0.29	0.20	-0.57	-0.58	-0.09	?
Leather	3.10	2.66	1.49	2.12	1.68	0.51	+
Primary textiles and textile products	-1.23	-1.28	-1.45	-1.62	-1.67	-1.84	-
Clothing	3.59	3.54	4.34	4.37	4.32	5.12	+
Wood	0.55	0.53	0.52	0.53	0.51	0.50	+
Furniture and fixture	1.25	1.19	1.80	1.67	1.62	2.22	+
Paper and allied products	-1.79	-1.44	-1.91	-1.44	-1.09	-1.56	-
Printing and publishing	3.82	3.82	4.73	3.45	3.45	4.36	+
Primary metal	0.98	0.97	1.11	0.71	0.69	0.84	+
Fabricated metal products	1.63	2.04	2.25	1.31	1.72	1.92	+
Machinery	-1.31	-1.29	-0.97	-1.81	-1.79	-1.46	-
Transportation equipment	-2.74	-2.71	-3.94	-3.22	-3.19	-4.42	-
Electrical and electronic products	-3.62	-3.60	-4.31	-4.46	-4.44	-5.16	-
Non-metallic mineral products	-1.88	-1.95	-1.02	-1.37	-1.44	-0.51	-
Refined petroleum and coal	5.81	5.71	2.63	6.32	6.21	3.13	+
Chemical products	-0.78	-0.83	-1.17	-1.15	-1.21	-1.54	-

TABLE 5

Annualized growth rate of energy intensity indicators from 1976 to 1996 in Ontario (%)

	Theil quantity index divided by			*Joules divided by*			
	Production Value	***Shipments Value***	***Value Added***	***Production Value***	***Shipments Value***	***Value Added***	
Total manufacturing	-2.41	-2.52	-2.01	-2.88	-3.00	-2.48	-
Food and beverage	-3.81	-3.92	-3.21	-1.59	-1.70	-1.00	-
Rubber and plastic products	-1.94	-2.10	-2.15	-3.28	-3.43	-3.48	-
Leather and allied textile products	1.10	0.85	4.19	-0.17	-0.42	2.92	?
Primary textiles and textile products	-1.62	-1.84	-2.29	-2.59	-2.82	-3.26	-
Clothing	1.45	2.27	1.53	1.62	2.44	1.71	+
Wood	-1.13	-1.31	-1.23	-1.20	-1.38	-1.30	-
Furniture and fixture	-0.96	-1.16	-0.30	-1.28	-1.48	-0.62	-
Paper and allied products	-0.97	-0.81	-1.05	-1.43	-1.27	-1.50	-
Printing and publishing	0.60	0.46	1.64	0.40	0.26	1.44	+
Primary metal	-1.43	-1.60	-1.13	-1.80	-1.97	-1.50	-
Fabricated metal products	0.13	0.28	0.14	0.47	0.61	0.48	+
Machinery	-2.32	-2.50	-2.46	-3.14	-3.32	-3.28	-
Transportation equipment	-1.99	-2.03	-1.35	-2.32	-2.35	-1.68	-
Electrical and electronic products	-4.45	-4.60	-5.59	-5.22	-5.37	-6.36	-
Non-metallic mineral products	-1.64	-1.61	-0.72	-1.44	-1.41	-0.51	-
Refined petroleum and coal	2.89	2.89	3.10	3.25	3.25	3.46	+
Chemical products	-3.88	-4.01	-4.40	-4.73	-4.86	-5.25	-

TABLE 6

Annualized growth rate of energy intensity indicators from 1976 to 1996 in Alberta

(%)

	Theil quantity index divided by			*Joules divided by*			
	Production Value	***Shipments Value***	***Value Added***	***Production Value***	***Shipments Value***	***Value Added***	
Total manufacturing	0.64	0.54	0.03	0.55	0.45	-0.06	?
Food and beverage	0.09	0.02	0.52	0.24	0.17	0.68	+
Clothing*	2..15	2.28	3.86	3.51	3.63	5.21	+
Wood	1.11	0.90	-0.55	0.60	0.39	-1.07	?
Furniture and fixture	2.21	2.09	3.06	3.44	3.31	4.28	+
Paper and allied products	0.05	0.27	0.17	-2.44	-2.23	-2.33	?
Printing and publishing	3.43	3.28	4.52	3.49	3.34	4.58	+
Primary metal	-0.31	-0.44	-1.31	-1.89	-2.01	-2.89	-
Fabricated metal products	3.90	4.43	4.10	4.41	4.94	4.61	+
Machinery	-3.59	-3.82	-2.02	-2.64	-2.87	-1.07	-
Transportation equipment	4.24	4.06	3.14	4.40	4.21	3.30	+
Electrical and electronic products	-8.15	-8.06	-9.81	-10.31	-10.22	-11.97	-
Non-metallic mineral products	0.83	0.68	1.74	0.33	0.18	1.24	+
Refined petroleum and coal	-1.05	-0.98	-4.73	-0.77	-0.70	-4.45	-
Chemical products	-1.54	-1.89	-2.69	-0.68	-1.04	-1.83	-
Other manufacturing	1.20	0.95	0.82	2.29	2.03	1.91	+

* Data from 1976 to 1978 are missing

TABLE 7

Annualized growth rate of energy intensity indicators from 1976 to 1996 in British Colombia

(%)

	Theil quantity index divided by			*Joules divided by*			
	Production Value	***Shipments Value***	***Value Added***	***Production Value***	***Shipments Value***	***Value Added***	
Total manufacturing	-1.10	-1.23	-0.21	-0.94	-1.07	-0.05	-
Food and beverage	0.35	0.10	1.37	0.64	0.40	1.67	+
Textile*	-7.99	-7.88	-10.01	-8.11	-7.99	-10.13	-
Clothing	1.40	1.26	2.92	3.25	3.11	4.77	+
Wood	0.42	0.33	1.78	0.91	0.82	2.27	+
Furniture and fixture	3.67	3.45	4.53	5.67	5.46	6.53	+
Paper and allied products	0.47	0.55	2.93	0.09	0.17	2.55	+
Printing and publishing	0.70	0.58	1.61	3.04	2.92	3.96	+
Primary metal	-7.53	-8.19	-7.54	-4.02	-4.68	-4.03	-
Fabricated metal products	2.15	2.53	2.76	2.12	2.51	2.74	+
Machinery	0.58	0.47	0.76	5.07	4.96	5.25	+
Transportation equipment	4.24	4.18	4.99	4.17	4.12	4.93	+
Electrical and electronic products	-3.66	-3.62	-6.37	-3.47	-3.43	-6.18	-
Non-metallic mineral products	-2.56	-2.63	-1.57	-1.11	-1.19	-0.12	-
Refined petroleum and coal	-0.60	-1.19	-1.20	-0.46	-1.04	-1.05	-
Chemical products	-2.34	-2.47	-2.80	-1.83	-1.96	-2.29	-
Other manufacturing	1.22	1.05	1.04	3.57	3.40	3.39	+

TABLE 8

Principal components analysis:

Characteristic vectors and relative roots of the total manufacturing sector

Québec

		Characteristic vectors 1	2	3	4	5	6
Theil qty index divided by	production	0.38	0.43	-0.32	-0.49	0.28	-0.50
	shipments	0.37	0.42	-0.31	0.51	0.28	0.50
	value added	0.32	0.51	0.55	0.00	-0.58	0.01
Joules divided by	production	0.48	-0.39	-0.21	-0.50	-0.27	0.51
	shipments	0.47	-0.39	-0.21	0.49	-0.29	-0.50
	value added	0.41	-0.27	0.64	0.01	0.59	-0.01
Relative characteristic root (%)		88.34	7.88	3.60	0.18	~0	~0
Characteristic vector interpretation		EI	J/T	VA/(P,S)	-	-	-

Ontario

		Characteristic vectors 1	2	3	4	5	6
Theil qty index divided by	production	0.39	0.27	-0.43	0.52	-0.22	-0.52
	shipments	0.40	0.23	-0.45	-0.51	-0.35	0.44
	value added	0.36	0.66	0.34	-0.03	0.56	0.08
Joules divided by	production	0.43	-0.45	-0.05	0.51	0.22	0.55
	shipments	0.44	-0.48	-0.08	-0.46	0.37	-0.47
	value added	0.41	-0.09	0.70	-0.02	-0.58	-0.08
Relative characteristic root (%)		99.45	0.32	0.21	0.02	~0	~0
Characteristic vector interpretation		EI	-	-	-	-	-

Alberta

		Characteristic vectors 1	2	3	4	5	6
Theil qty index divided by	production	0.34	0.47	0.34	-0.47	-0.26	-0.51
	shipments	0.33	0.45	0.27	0.51	-0.32	0.51
	value added	0.46	-0.33	0.57	0.06	0.59	0.01
Joules divided by	production	0.39	0.22	-0.45	-0.51	0.30	0.49
	shipments	0.38	0.20	-0.51	0.50	0.26	-0.49
	value added	0.52	-0.62	-0.18	-0.05	-0.56	-0.01
Relative characteristic root (%)		86.24	11.73	1.97	0.06	~0	~0
Characteristic vector interpretation		EI	(P,S)/VA	J/T	-	-	-

British Columbia

		Characteristic vectors 1	2	3	4	5	6
Theil qty index divided by	production	0.44	0.23	-0.38	0.50	-0.32	0.51
	shipments	0.44	0.29	-0.39	-0.49	-0.29	-0.50
	value added	0.50	-0.59	-0.28	-0.01	0.57	-0.02
Joules divided by	production	0.33	0.35	0.40	0.54	0.26	-0.50
	shipments	0.33	0.42	0.38	0.47	0.34	0.49
	value added	0.39	-0.47	0.56	-0.07	-0.56	0.02
Relative characteristic root (%)		86.05	9.85	4.03	0.07	~0	~0
Characteristic vector interpretation		EI	(P,S)/VA	T/J	-	-	-

EI = Energy intensity J = Joules T = Theil quantity index

VA = Value added P = Production S = Shipments

TABLE 9

Relative size of characteristic roots and the interpretation of characteristic vectors (%)

		Total manufacturing	Food and beverage	Rubber and plastic products	Leather and allied products	Primary textiles and textile products*	Clothing**	Wood	Furniture and fixture	Paper and allied products	Printing, publishing	Primary metal	Fabricated metal products	Machinery	Transportation equipment	Electrical and electronic products	Non-metallic mineral products	Refined petroleum and coal	Chemical products	Other manufacturing
Québec	EI	88.3	89.7	i.d.	97.8	99.2	98.8	98.8	97.4	83.9	99.8	96.0	93.2	96.4	94.7	97.0	98.7	90.6	94.9	i.d.
	T/J	7.9	0.6		0.6	***	***	0.2	1.0	13.2	***	***	2.0	2.0	***	0.4	***	0.1	1.8	
	VA/(P,S)	3.6	7.9		***	***	0.9	1.0	1.6	1.9	0.1	***	4.6	1.0	4.1	2.5	***	9.3	3.3	
	Residual	0.2	1.8		1.7	0.8	0.3	~0	~0	1.0	0.1	4.0	0.2	0.6	1.2	0.1	1.3	~0	~0	
Ontario	EI	99.5	94.4	98.2	92.4	95.6	94.6	99.4	92.4	92.5	94.1	97.2	97.0	95.3	90.6	99.1	93.5	94.5	99.1	i.d.
	T/J	0.3	4.8	***	1.2	2.9	0.9	0.2	0.6	***	0.3	0.6	***	0.7	0.5	0.1	0.8	0.5	0.1	
	VA/(P,S)	0.2	0.8	***	6.4	1.0	4.4	0.4	6.9	***	5.6	2.0	***	3.3	8.8	0.7	5.7	5.0	0.8	
	Residual	~0	~0	1.8	~0	0.5	0.1	~0	0.1	7.5	~0	0.2	3.0	0.7	0.1	0.1	~0	~0	~0	
Alberta	EI	86.2	84.1	i.d.	i.d.	i.d.	88.1	85.4	94.9	88.0	89.2	96.9	97.6	80.7	95.3	98.3	93.4	61.7	96.2	95.1
	T/J	2.0	2.3				11.3	***	3.9	10.5	10.4	0.8	1.5	14.7	2.7	0.6	1.7	1.9	0.6	4.7
	VA/(P,S)	11.7	13.6				0.6	***	1.1	1.3	0.4	2.3	0.5	4.3	2.0	***	4.8	36.3	3.1	0.2
	Residual	0.1	~0				~0	14.6	0.1	0.2	~0	~0	0.4	0.3	~0	1.1	0.1	0.1	0.1	~0
B.C.	EI	86.0	92.8	i.d.	i.d.	94.1	88.1	89.1	93.3	91.2	88.4	97.6	95.9	91.3	94.9	81.1	86.8	59.6	95.8	91.7
	T/J	4.0	***			***	11.3	2.1	5.7	0.4	11.2	1.9	2.8	7.6	4.2	16.5	12.4	6.8	0.5	6.9
	VA/(P,S)	9.8	***			0.5	0.6	8.7	1.0	8.2	0.3	0.4	***	1.0	0.8	2.2	0.7	33.3	2.7	1.4
	Residual	0.2	7.2			5.4	~0	0.1	~0	0.2	0.1	0.1	0.3	0.1	0.1	0.2	0.1	0.3	~0	~0

i.d.: Incomplete data

* The data from 1992 to 1996 are missing for B.C.

** The data from 1976 to 1978 are missing for Alberta

*** No contrast is found

TABLE 10

Annualized growth rate of energy intensity from 1976 to 1996

based on the first principal component (%)

	Total manufacturing	Food and beverage	Rubber and plastic products	Leather and allied products	Primary textiles and textile products*	Clothing**	Wood	Furniture and fixture	Paper and allied products	Printing, publishing	Primary metal	Fabricated metal products	Machinery	Transportation equipment	Electrical and electronic products	Non-metallic mineral products	Refined petroleum and coal	Chemical products	Other manufacturing
Québec	0.00[d]	0.08[d]	i.d.	2.01[b]	-1.50[a]	4.20[b]	0.53[b]	1.64[b]	-1.67[d]	4.22[a]	0.96[b]	1.98[c]	-1.22[b]	-3.58[c]	-4.30[b]	-1.24[b]	2.95[c]	-1.19[c]	i.d.
Ontario	-2.37[a]	-2.98[c]	-2.54[b]	3.26[c]	-2.41[b]	1.78[c]	-1.24[a]	-0.82[c]	-1.16[c]	1.09[c]	-1.39[b]	0.28[b]	-2.70[b]	-1.69[c]	-5.48[a]	-1.09[c]	3.22[c]	-4.58[a]	i.d.
Alberta	0.16[d]	0.49[d]	i.d.	i.d.	i.d.	3.63[d]	-0.01[d]	3.13[c]	-0.85[d]	3.98[d]	-1.79[b]	4.33[b]	-2.46[d]	3.72[b]	-9.25[b]	1.17[c]	-4.40[d]	-1.88[b]	1.09[b]
B. C.	-0.51[d]	1.20[c]	i.d.	i.d.	-9.21[c]	2.91[d]	1.60[d]	4.73[c]	2.26[c]	1.98[d]	-5.54[b]	2.57[b]	3.86[c]	4.68[c]	-5.43[d]	-1.55[d]	-1.11[d]	-2.45[b]	1.88[c]

i.d.: incomplete data

* The data from 1992 to 1996 are missing for B.C.

** The data from 1976 to 1978 are missing for Alberta.

Relative size of first characteristic root: a ~ 99.0-100.0%, b ~ 95.0-98.9%, c ~ 90.0-94.9%, d ~ < 90.0%

Data Appendix

A.I Manufacturing output

Data on shipments and value added come from Statistics Canada, Manufacturing Industries of Canada, # 31-203. Only manufacturing activities are included. There are no data on value of production and we built the series by adding together value added, cost of materials and costs of purchased fuels and electricity.

Statistics Canada adopted a new standard industrial classification (SIC) in 1980. In order to have coherent definitions of industries for the whole period, we added two industries into one in three cases: food (10) and beverage (11), rubber (15) and plastic products (16), and primary textile (18) and textile products (19).

Statistics Canada, Industry Price Index, # 62-011 presents national industry selling price indices and they are used to obtain value of shipment and value of production in constant dollars at the province level. Statistics Canada, Gross Domestic Product by Industry, # 15-001 provides national figures on value added of total manufacturing activity by industry in 1992 dollars. This is used together with current value presented in # 31-203 to build national price indices by industry and the latter are used to correct the provincial figures for inflation.

No data could be gathered on some industries due mostly to confidentiality.

A.2 Energy

The data on energy use by industry (prices and quantities) come from Statistics Canada, Consumption of Purchased Fuels and Electricity, # 57-208.

In 1985, 1986, and 1990 only the information on energy expenditures were published and in 1987, 1988, and 1989, no data were published at all. Here is how we bridged the gaps in the series: for each series that presented such a gap, we identified another series that has a close relationship with the missing series and then the gap was filled by letting the incomplete series grow relatively at the same rate as the observed series over the missing years. For energy quantities, we used Statistics Canada, Quarterly Report on Energy Supply-Demand in Canada, # 57-003. For electricity prices, we used Statistics Canada, Electric Power Generation, Transmission and Distribution, # 57-202. For natural gas prices, we used Statistics Canada, Natural Gas Transportation and distribution, # 55-002. The information on diesel, heavy fuel, and gasoline prices comes from Statistics Canada, Energy Statistics Handbook, # 57-208. The prices of light fuel, kerosene, LPG and coal were obtained from Statistics Canada, Industry Price Indexes, # 62-011.

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