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ENERGY ANALYSIS OF CANADIAN EXTERNAL TRADE: 1971 and 1976

by

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ABSTRACT. Methodology and results are presented to show that Canadian exports (dominated by raw and semi-finished goods) were significantly more energy intensive than imports (dominated by manufactured goods) in both 1971 and 1976 - the net surplus of export energy requirements over import energy requirements totaled 9% of domestic use of energy in 1971. Exports of goods and services were 26% more energy intensive per dollar than imports in 1976. Canadian intensiveness of energy use, as measured by the aggregate energy/GDP ratio, changed little over this period. Decomposition of commercial energy requirements per dollar of GDP reveals that final consumption patterns and direct energy use coefficients (the use of energy per constant dollar of production in each commercial sector) moved in the direction of increased energy intensity between 1971 and 1976; these effects were largely counteracted by shifts in the pattern of trade.

Key Words: energy analysis, external trade.

Introduction

The hypothesis that the factor endowment of a country will be reflected in its trade (made precise in the Heckscher-Ohlin theorem) was explored empirically by Leontief [1] in 1953, with surprising results: in what has come to be known as the "Leontief paradox" his Input/Output analysis of the factor content of American trade revealed that the United States exported goods and services which were more labour intensive and less capital intensive than its imports. Work since that date has focused on the quality of the factors measured (e.g. labour skills) and on different kinds of factors - the study by Postner [2], for instance, looked at renewable and non-renewable resource requirements in Canadian trade. The present study examines a resource of great importance in the 1970's and 80's, primary energy.

The scale and structure of external trade in goods and services has profound effects on the overall energy intensiveness of any economy. This study is concerned with the comparison of the energy required to produce the bill of goods which Canada exports with the energy savings (or, more accurately, foregone energy requirements) associated with the import bill of goods. There is an intrinsic interest in exploring the extent to which Canada has tended to be a net exporter of energy "embodied" in its goods trade, but there are practical implications as well, particularly with respect to Canada's dealings with the International Energy Agency and to the relationship between Canadian energy policy and industrial development policy.

Equally worth investigating are structural changes, especially in energy consumption patterns, before and after the oil shock of 1973. To examine this the present study will look at shifts in the intensity of energy use in the commercial sector between 1971 and 1976, and will decompose these shifts in an effort to compare effects due to trade with other structural changes.

Table 1 provides the necessary background for what follows. In it we see the structure of production and trade for primary energy commodities in 1971 and 1976. The notion of "primary equivalent" employed is that of standard international practice: secondary energy products (such as gasoline and fuel oil) and all electricity are counted as the amount of thermal energy which would be required for their production. "Hydro electricity" includes nuclear generation in this and following tables.

Aggregate domestic product and trade figures are shown in Table 2, as well as energy indicators such as the energy/GDP ratio, the self-reliance ratio (the ratio of total primary energy production to domestic use), and the trade ratio (the average of exports and

Table 1
Primary Energy Production and Trade

1971
Petajoules Primary Equivalent

	Production	Exports	Imports	Domestic Supply (DS)	Share of DS
Coal	405	205	478	678	9.7%
Nat. Gas	2404	961	15	1458	20.8%
Hydro El.	1732	76	35	1691	24.1%
Crude oil	3298	1670	1495	3123	44.5%
PLPG	163	97	0	66	0.9%
Total	8002	3009	2023	7016	100.0%

1976
Petajoules Primary Equivalent

	Production	Exports	Imports	Domestic Supply (DS)	Share of DS
Coal	620	343	439	716	8.2%
Nat. Gas	2866	1006	4	1864	21.3%
Hydro El.	2406	134	38	2310	26.4%
Crude oil	3237	1058	1616	3795	43.4%
PLPG	242	182	0	60	0.7%
Total	9371	2723	2097	8745	100.0%

Notes: Source: Ref. 3
PLPG - primary liquefied petroleum gases.

imports in proportion to domestic use).

These tables display two static elements in the aggregate energy picture: the shares of fuels in domestic energy supply, and the energy intensity (as measured by the energy/GDP ratio). The trade-related indicators show more movement: both self-reliance and the proportion of trade to domestic use decline significantly from 1971 to 1976 - we see, therefore, both a decline in the surplus of Canadian production over domestic needs and a reduction in the relative size of trade in energy products in comparison with the domestic market.

Table 2
Aggregate Economic and Energy Indicators

Millions of 1971 dollars

	1971	1976
GDP [1]	95635	120113
Exports	20668	24616
Imports less re-exports	18993	27645

Energy Indicators

	1971	1976	
Primary Energy/GDP	73.4	72.8	Megajoules/ 1971 $
Self-reliance ratio	1.14	1.07	
Trade ratio	0.36	0.28	

Notes: [1] Source: Ref. 4

Self-reliance is the ratio of primary energy production to domestic use of primary energy. The trade ratio is the average of exports and imports of primary energy in proportion to domestic use.

The object of the analysis that follows is to dig beneath the aggregate production and trade figures to reveal how external trade in goods and services influences overall energy requirements and to examine how these and other influences changed from 1971 to 1976. The methodological basis of the study is Input/Output energy analysis, first described by Herendeen [5] and more fully expounded by Flaschel [6]. Working papers produced at Statistics Canada presented Canadian experience in the methodology [7] and its application, including an energy analysis of external trade using 1966 data [8].

The technical details of I/O energy analysis are reserved for the Appendix. All dollar figures in this study are constant 1971 dollars.

The Energy Analysis of External Trade

Where Table 1 displays the trade in energy products, we now turn our attention to the energy required to produce the goods which Canada trades. This will shed new light on Canadian external trade.

The power of Input/Output (I/O) based energy analysis is that it permits the estimation of direct and indirect use of energy to produce any of the spectrum of goods and services Canadians consume. As an example, I/O energy analysis permits measurement of both the energy used on the production line in the manufacture of an automobile (the direct energy) and the energy required to produce the steel, glass, plastic, rubber, etc., of which the auto is constituted (the indirect energy). The total direct and indirect primary energy needed to produce a given product will be referred to as the energy requirements of that product.

To estimate the net effect of external trade on Canadian energy consumption two I/O simulations were carried out, one in which total final consumption including exports and imports was maintained at historical levels, and the second in which there was the same final consumption but exports and imports were set to zero. The "without trade" variant therefore simulates a hypothetical closed Canadian economy.

In both simulations what is being measured is the energy requirement of total final demand (i.e. direct and indirect energy used to produce the goods and services) rather than the amount of energy actually exported, imported, or consumed by households or governments. These calculations are summarized for 1971 and 1976 in Table 3.

We can conclude from Table 3 that Canada's pattern of trade entailed increases in energy requirements in both 1971 and 1976, with the effect being more pronounced in 1971; this is equivalent to saying that export energy requirements were greater than the energy requirements foregone in imported goods.

The earlier working paper by Hamilton [8] arrived at similar results about the dominance of export energy requirements. Although the methodology was different in its details, this paper showed that in 1966 the surplus of export energy requirements over imports amounted to 5.2% of domestic use, or 8.5% of commercial energy usage - the corresponding 1971 figures from Tables 1 and 3 are 9% and 14.3%.

Further light can be shed on these results by looking at the energy intensiveness of exports and imports. We define energy intensiveness of a bill of goods and services to be the direct and

Table 3
Canada Total Primary Energy Requirements
With and Without External Trade

Petajoules

	1971	1976
With trade	4607	5860
No trade	3947	5449
% difference	-14.3%	-7.0%

Notes: Percent difference is with respect to the "with trade" figure in each year.

indirect energy required by the commercial sector (i.e. all primary, secondary and service industry) to deliver one dollar of the products to a final user.

Table 4 compares the energy intensiveness of exports and imports. To give a common basis for the comparison, imports are restricted to competitive imports (i.e. those for which there is a competing Canadian producer). This table shows export energy intensity to be nearly constant between 1971 and 1976 at about 120 megajoules per 1971 dollar. Import energy intensity declines substantially over these years but remains from 22% to 26% less than export energy intensiveness. The apparent discrepancy between Tables 3 and 4 is explained by referring to Table 2: from 1971 to 1976 the current account trade balance in constant dollars changed from a state of modest surplus to one of more substantial deficit.

A word needs to be said about the methodology used in measuring import energy intensiveness. Tables 3 and 4 show the result of measuring the energy requirements of imports as if they were produced in Canada using Canadian technology. It is arguable that this overstates the "actual" energy required to produce the goods Canada imports since our trading partners all experienced sharper energy price increases than we did in the 1970's. However, it is also arguable that measuring imports according to domestic energy requirements foregone is the only meaningful way to calculate import energy "savings" which are comparable to export energy "costs", and, moreover, that the only relevant savings are those of energy that <u>would</u> be required if production took place in Canada.

Having noted the decrease in import energy intensiveness between

Table 4
Energy Intensiveness of Exports and Imports
Megajoules per 1971 dollar

	1971	1976
Exports	121.8	119.8
Imports	94.5	88.3
% difference	-22.4%	-26.3%

Notes: Percentage difference is with respect to the export figure in each year.

Imports are competitive imports less re-exports.

1971 and 1976, it is possible to ask to what extent this decrease was owing to changes in techniques of production (and in particular the energy-using characteristics of these techniques) as compared with changes in the mix of goods and services imported. As outlined in the Appendix, I/O energy analysis permits the decomposition of the difference in import energy intensiveness into two terms representing precisely these effects. The results of this decomposition can be seen in Table 5.

Table 5
Import Energy Intensity Change Decomposition
Megajoules per 1971 dollar

1971 Intensity	94.5
1976 Intensity	88.3
Difference	-6.2
Energy intensity term	0.8
Import composition term	-7.0

The "energy intensity term" in Table 5 measures the effects of changes in production techniques including energy utilization; it shows a minor increase in the energy intensiveness of the average import. The effects owing to shifts in the composition of imports are more pronounced and negative. We see, therefore, that the decrease in energy intensiveness of imports from 1971 to 1976 was

almost entirely owing to changes in the mix of imports.

Structural Changes in Energy Requirements

The preceding section examined the energy requirements of exports and imports and how these changed from 1971 to 1976. This raises the question of what other changes occurred in the patterns of energy consumption between these two years and how the effects owing to trade compared with them.

The starting point in this analysis is to compare the total commercial energy use per constant dollar of GDP in each year - dividing by GDP controls for the effects economic growth. Using techniques similar to those employed in the analysis of changes in import energy intensiveness, it is possible to decompose the difference in commercial energy use per dollar of GDP between 1971 and 1976 into a series of discrete terms. The terms we choose to highlight here are: technology, final demand, imports (both scale and mix), exports (scale and mix), and direct energy use coefficients.

These terms require some explanation:

- Technology: this term combines the effects of changing input structures and market shares of all commercial sectors.
- Final demand: shifts in the quantity and mix of goods and services going to households, governments, investment and inventory accumulation are combined in this term.
- Imports: separate terms for the changing scale of imports (their proportion to GDP) and changes in the mix of imports are represented.
- Exports: as for imports, separate terms for scale and composition are calculated.
- Direct energy use coefficients: a fundamental determinant of energy intensiveness is the quantity of energy consumed per constant dollar of production in each sector. The aggregate effect of changes in these coefficients is measured by this term.

Table 6 displays the change in commercial energy use per dollar of GDP between 1971 and 1976 and its decomposition. Negative figures in this table indicate terms tending to decrease the energy intensity of the commercial sector in 1976 compared with 1971. Note that the change in the aggregate is negligible, 0.6%. However, there are some significant changes in individual

Table 6
Decomposition of Commercial Energy Use
Per Dollar of GDP

Megajoules per 1971 Dollar

1971 primary energy requirements	48.2	
1976 primary energy requirements	48.4	
Change (1976-1971)	0.3	(0.6%)
Changes in commercial energy use per dollar of GDP owing to:		
Technology	-1.7	(3.6%)
Final demand	3.0	(6.2%)
Import mix	1.3	(2.6%)
Import scale	-3.0	(6.2%)
Export mix	-1.6	(3.2%)
Export scale	-1.5	(3.0%)
Direct Energy Coeff.	3.7	(7.7%)
Selected aggregates of these terms:		
Demand, trade & tech.	-3.5	(7.2%)
Demand & trade	-1.8	(3.6%)
Imports	-1.7	(3.6%)
Exports	-3.0	(6.2%)

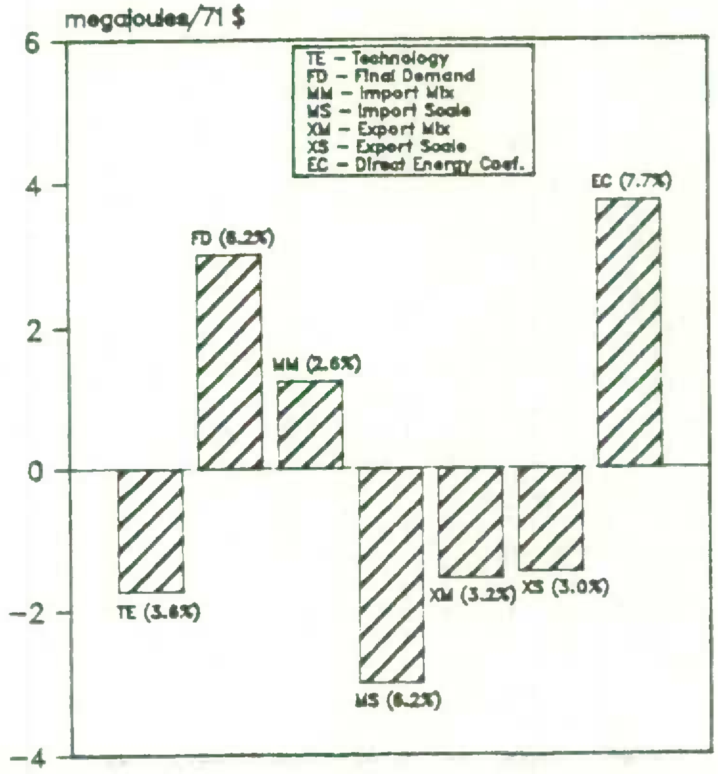
Note: Percentages are absolute values of proportion of 1976 commercial primary energy use.

components, especially final demand, import scale, and direct energy use coefficients, which stand out in Figure 1.

Noting that the combined effect of export scale and mix is also significant, we can conclude from this decomposition that there were strong tendencies for the structure of final demand and direct energy use per unit of output in the commercial sector to increase energy intensiveness between 1971 and 1976; structural change in external trade largely canceled these effects.

Figure 1

DECOMPOSITION OF DIFFERENCE IN ENERGY REQUIREMENTS PER $ GDP 1976 – 1971



Discussion and Summary

The result that Canadian exports are more energy intensive than Canadian imports appears to be robust, having been measured for 1966, 1971 and 1976. We need not look far for the reason: Canadian exports are weighted towards raw and semi-finished goods, Canadian imports towards manufactures. The two examples in Table 7 are typical: for both paper products and iron and steel products the energy intensity per dollar reaches a peak at the semi-finished stage and declines steeply for the finished product.

Processes of extraction, separation, and concentration dominate the production chain up to the point of semi-finished products,

Table 7
Selected Energy Intensities, 1976
Megajoules per 1971 $

Pulpwood & chips	62.4	Iron ores & concentr.	198.6
Pulp	259.0	Pig Iron & steel ingots	232.3
Paper end prod.	105.9	Pipe & sheet metal	118.6

and in these stages energy inputs are high, value added low. Beyond the semi-finished state (i.e. through fabrication and assembly) the energy inputs are low, value added high. The initial rise and subsequent decline of the energy intensities by production stage seen in Table 7 is the result. However, it would require a more detailed investigation than the current study to prove this in detail.

Regarding changes between 1971 and 1976 we note that the energy intensiveness of both exports and imports decreased, the former by over 2 Megajoule/$ (a 1.7% decline), and the latter by over 6 Megajoule/$ (a decline of 7.0%). The import energy intensiveness was actually pushed upward slightly by changes in direct energy use coefficients, but changes in the composition of imports brought this sharply down.

Total commercial energy use per dollar of GDP (in constant dollars) changed by an insignificant amount over these years as, indeed, did the total energy/GDP ratio. Beneath this apparent stasis, however, is a spectrum of shifts in the constituents of the total: production technology, import scale, and exports (both scale and composition) moved in the direction of decreased energy intensity from 1971 to 1976; final consumption, import mix, and direct energy use coefficients moved towards increased intensity. Large increases in intensity associated with shifts in final demand and energy use coefficients were largely counteracted by changes in the structure of trade.

There are two unexpected results that are noteworthy: the apparent increase in direct energy use coefficients (corresponding to increased energy use per unit of production), and the minimal shifts in the aggregate energy/GDP ratio and fuel shares in domestic supply. The second of these has several likely explanations: (i) the energy-using stock items in the economy have long lifetimes (e.g. industrial boilers, private automobiles); (ii) the development of new energy conserving technologies takes time (e.g. designing and manufacturing efficient furnaces); and (iii) energy supply facilities, especially for electricity, have long construction times.

Table 8
Primary Energy Production and Trade
1981

Petajoules Primary Equivalent

	Production	Exports	Imports	Domestic Supply (DS)	Share of DS
Coal	970	464	449	955	10.1%
Nat. Gas	2526	804	0	1722	18.2%
Hydro El.	3162	370	15	2806	29.7%
Crude oil	3093	366	1138	3865	40.8%
PLPG	315	200	0	115	1.2%
Total	10066	2204	1602	9463	100.0%

Aggregate Economic Indicators
Millions of 1971 dollars

GDP [1]	139485
Exports	30917
Imports less re-exports	32055

Aggregate Energy Indicators

Primary Energy/GDP	67.8 Megajoules/1971 $
Self reliance ratio	1.06
Trade ratio	0.20

Notes: [1] Source: Ref. 4

Self-reliance is the ratio of primary energy production to domestic use of primary energy. The trade ratio is the average of exports and imports of primary energy in proportion to domestic use.

To give some indication of the difference another five years makes, Table 8 displays for 1981 the same summary information as appeared in Tables 1 and 2. Compared with 1976, we see exports of primary electricity increasing by nearly a factor of three, while those of crude oil fall by roughly the same factor. In the shares of domestic supply there is a significant increase in electricity and corresponding decline in crude oil. The primary energy/GDP ratio declines by nearly 7% and the trade ratio by 0.08.

Many of the results of this study relating to changes from 1971 to 1976 can be explained by changing relative prices. For instance, we note that imports shifted towards less energy intensive goods and services over this interval, and that there was a decline in trade in energy commodities as oil imports became expensive and domestic oil more scarce. The exception to this tidy picture is the direct use of energy per unit of production in the commercial sector, which actually increased slightly over the period in question.

Canada has traditionally been energy-rich and an exporter of energy products. This study reveals the degree to which this extends to Canada's being a significant net exporter of indirect energy through its structure of trade. In 1971 increased energy use inherent in Canadian trade patterns was over 14% of commercial energy use, over 9% of total domestic use. This is a consequence of exports being significantly more energy intensive per dollar than imports, amounting to some 26% in 1976.

Appendix: I/O Based Energy Analysis

The Canadian Input/Output system distinguishes 191 industries and 602 commodities in a rectangular accounting framework. To construct a working model two assumptions are invoked: (i) industry technology, wherein the inputs of commodities to each industry are held to be fixed in proportion to total industry output, and (ii) fixed market shares, whereby the proportion of the total market for a given commodity is assumed to be constant for each producing sector. By convention the technology matrix is denoted B (and is commodity by industry in dimension); the market share matrix (industry by commodity) is denoted D. For vectors of industry production g (i.e. the sum of all commodities produced by each sector), commodity production q, exports x, imports less re-exports m, and other final demand f, the following hold:

$$q = Bg + f + x - m \qquad (1)$$

$$g = Dq. \qquad (2)$$

The first identity says that commodity production is the sum of intermediate demand, final demand (including consumers expenditure, government expenditure, investment, and inventory accumulation), and exports, less imports. The second just states the market share assumption mathematically. For our purposes B and D are dimensionless coefficients, and all other vectors are measured in dollars. Based on this we can solve for industry output by substituting (1) into (2):

$$g = (I-DB)^{-1}D(f+x-m). \qquad (3)$$

Defining e to be a row vector of total direct primary energy equivalents consumed per dollar of output in each commercial sector, direct plus indirect energy requirements per dollar of demand of each commodity (energy intensities) E may be expressed as:

$$E = e(I-DB)^{-1}D. \qquad (4)$$

Complete specification of the construction of the Canadian I/O tables is given in reference [9]. The methodology for constructing the direct energy requirement coefficients is outlined in working paper [10]. The quality of these coefficients is enhanced by the availability of much of the important energy data in physical quantity in the Canadian statistical system (i.e. for agriculture, mining, manufacturing, utilities and transportation), eliminating the need to estimate physical quantities.

Given the preceding expression for energy intensities, the energy requirements to produce any bill of goods (measured in dollars)

can be obtained by taking the inner product of E and the bill of goods. According to this definition, energy requirements are the measure of energy consumption in the commercial sector; in National Accounting terms they represent the intermediate consumption of energy.

We should note from expressions (3) and (4) that the technology terms - $(I-DB)^{-1}D$ - are the equivalent of the Leontief inverse, and measure the inter-industry relationships with respect to a "pure" Canadian technology, with no leakages of intermediate imports. The net effect of external trade on commercial energy requirements is measured as the difference of the following two expressions:

$$t_1 = e(I-DB)^{-1}D(f+x-m) \tag{5}$$
$$t_2 = e(I-DB)^{-1}Df \tag{6}$$

Expression (5) represents the energy required to deliver demand f to final users combined with exports of goods x and imports of goods m - in this regard goods imports may be viewed as foregone energy requirements. Expression (6) calculates the energy required to deliver the same demand f to final users, but in the absence of trade.

The difference in import intensiveness can be decomposed into effects owing to changing commodity energy intensities and changing patterns of imports. Let the superscript "*" indicate 1971; arrays without this superscript represent 1976 figures. The change in import intensiveness can be represented as:

$$\begin{aligned} M-M^* &= Em - E^*m^* \\ &= (E-E^*)m + E^*(m-m^*) \end{aligned} \tag{7}$$

Here M is the energy intensity of imports for 1976, and m the pattern or composition vector (i.e. competitive imports less re-exports normalized to $1).

The decomposition of aggregate measures employed in expression (7) can be used effectively in examining the components of total commercial energy use per dollar of GDP and how these changed from 1971 to 1976. In what follows we assume that f, x, m, and g are all measured in constant dollars per constant dollar of GDP. Let S be the total commercial energy required per dollar of GDP and, for convenience of exposition, let:

$$R = (I-DB)^{-1}D, \quad d = f+x-m.$$

If, as previously, the superscript "*" represents values for 1971, then:

$$S-S^* = eg - e^*g^* = e(g-g^*) + (e-e^*)g^*. \quad (8)$$

The first term in (8) represents changes in commercial energy intensiveness owing to the structure of demand and production; the second represents changes owing to the structure of commercial energy use, that is, in the direct energy use coefficients e of expression (4). This expression can be further decomposed as follows:

$$g-g^* = Rd - R^*d^* = (R-R^*)d + R^*(d-d^*) \quad (9)$$

Changes in commercial energy intensiveness owing to changes in technology (or, more precisely, changes in input coefficients and market shares) are captured by the first term in (9), while the second represents changes owing to the structure of demand. This latter term decomposes in an obvious way into individual terms representing changes in the structure of final demand, exports, and imports. For exports and imports it is worth detailing the differences owing to scale (i.e. the proportion of GDP) and to composition. If X is the total proportion of exports in GDP for 1976, and t the normalized vector of exports, then:

$$x-x^* = Xt - X^*t^* = (X-X^*)t + X^*(t-t^*). \quad (10)$$

Decompositions of the difference of products such as those appearing in expressions (7) through (10) are not unique; it is easy to prove that if there are n terms in the product then there are 2^{n-1} different decompositions possible. A check of alternative decompositions for the subject matter of this study yielded similar results.

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