Working Paper Series

An Examination of Change in Energy Dependence and Efficiency in the Six Largest Energy Using Countries — 1970–1988

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Working Papers Series
Issues in Macroeconomics
Research Department
Federal Reserve Bank of Chicago
January 1992 (WP-92-2)

FEDERAL RESERVE BANK OF CHICAGO

AN EXAMINATION OF CHANGE IN ENERGY DEPENDENCE AND EFFICIENCY IN THE SIX LARGEST ENERGY USING COUNTRIES--1970-1988

by

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8-29-91

Prepared for the Federal Reserve System Energy Conference, September 5-6, 1991, Denver, Colorado--sponsored by the Federal Reserve Bank of Kansas City.

The author gratefully acknowledges comments on earlier drafts by Kenneth Kuttner, Prakash Loungani, and Steve Strongin of the Federal Reserve Bank of Chicago. The views expressed herein do not necessarily reflect those of the aforesaid commentators nor of the Federal Reserve Bank of Chicago.

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World oil market fragility was demonstrated again in 1990 following the August 2 invasion of Kuwait by Iraq and the subsequent United Nations imposed embargo on oil shipments from Iraq and Kuwait. Concern about the potential cut-off of Middle East oil brought back memories of long lines at gas stations, dim lighting in offices, lower thermostats on furnaces and reduced use of air conditioners. In public debate, issues of energy dependence, efficiency, and conservation were again in vogue. Developments in the Middle East from August 1990 through February 1991 serve as an effective reminder of the importance of energy in general and petroleum in particular to the industrial economies.

The intent of this article is two fold. In order to set the stage, it first reviews recent developments in the oil markets. Next, it surveys concepts of energy and oil-use dependence as well as energy and oil-use efficiency. It proposes measures of dependence and efficiency and uses these measures to compare developments in the world's six heaviest consumers of energy--Canada, France, West Germany, Japan, the United Kingdom, and the United States--during the period 1970 to 1988.

RECENT DEVELOPMENTS

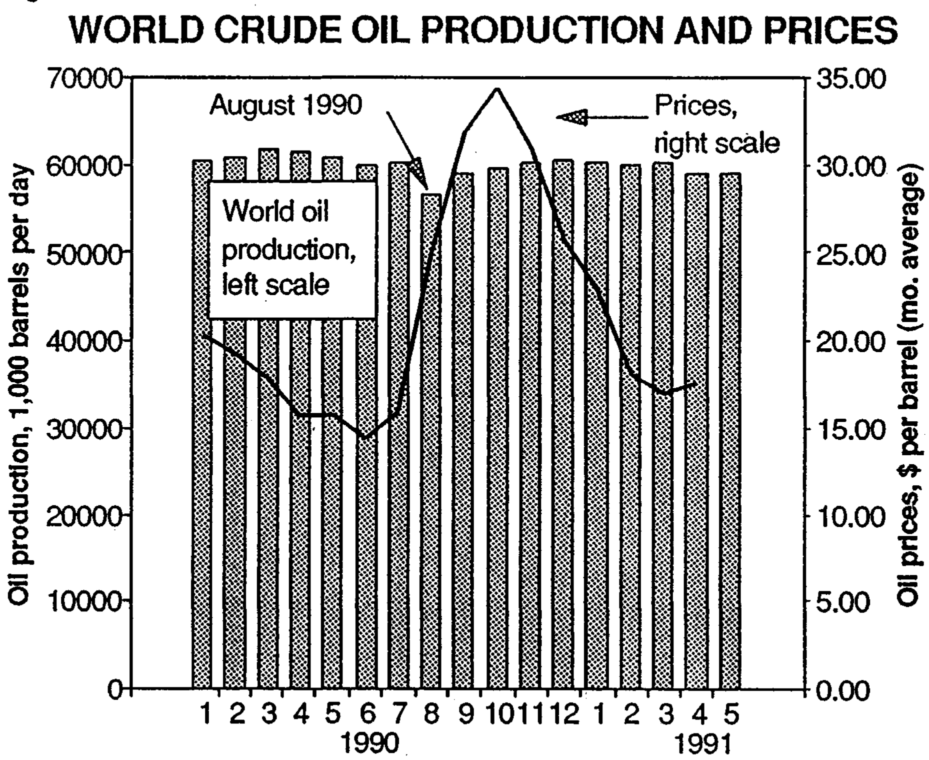
Following the U.N. embargo on oil shipments from Iraq and Kuwait, world crude oil production declined 6 percent in August, a reduction of 3.5 million barrels per day. However, initial fears of an oil shortage proved unfounded. Within days, other major oil exporters pledged to increase production to offset the 4.5 million barrels per day of lost Iraq and Kuwait oil. World crude oil production and prices are shown in Figure 1.

Nevertheless, oil prices soared, bringing on the fourth major price shock to world oil markets in less than two decades (counting the rapid decline in oil prices in 1986). Uncertainty in the markets intensified as multinational forces opposing the Iraqi move began to deploy in Saudi Arabia and the threat of military confrontation grew. Spot prices for crude oil peaked at over $40 per barrel in early October, up from $19 per barrel prior to the invasion of Kuwait.

By late November, oil production by the 11 remaining OPEC members, in particular Saudi Arabia, exceeded that of all 13 members of OPEC prior to the invasion, thus wiping out the Iraqi-Kuwaiti export deficit. World production returned to pre-August levels of 60-61 million barrels per day. In addition, world oil demand was slipping because of weakening economic conditions in oil importing countries and oil consumers' response to higher oil prices.

By mid-December, spot prices for crude had declined to well below $30 per barrel. Analysts were beginning to suggest that crude oil prices would once again drop to levels well below $20 per barrel during 1991, assuming a favorable resolution of the Persian Gulf situation.

Figure 1:



Source: CIA and U.S. Department of Energy.

With the initiation of the allied air offensive against Iraq on January 16, 1991, oil prices surged again, to more than $30 per barrel. However, it soon became apparent that oil production in the Gulf states would not be appreciably affected by the war, nor would shipping lanes in the area be disrupted. Oil prices promptly declined to the $20-$25 per barrel range.

The initiation of the land war by Coalition Forces on February 24 and its rapid conclusion contributed to a further easing of market tensions. Real economic factors once again dominated the market. Oil prices dropped into the $18-$20 per barrel range and day-to-day price variation decreased markedly.

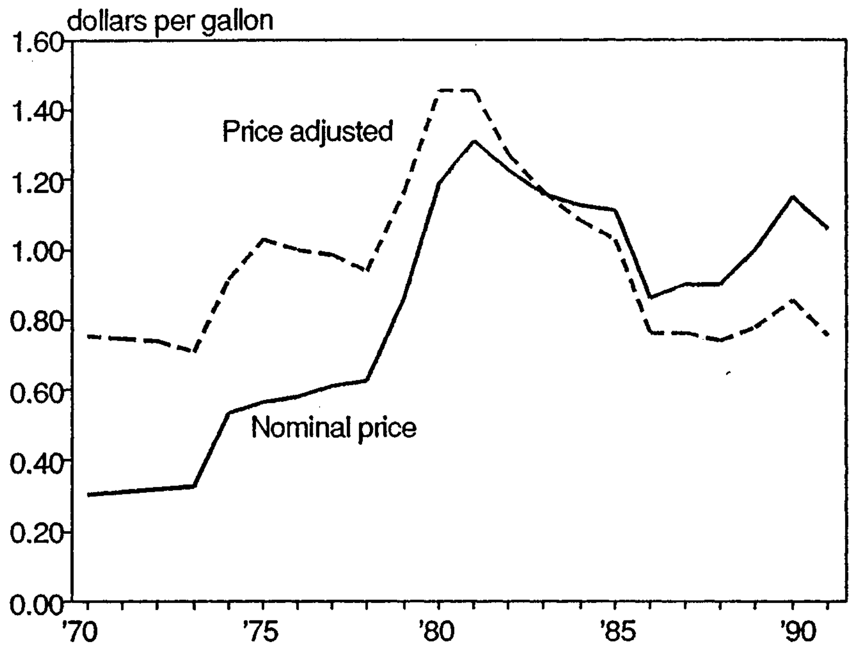
The lesson learned from Kuwait

Soaring oil prices once again raised the issue of the economic dependance of the world's economies on energy, in general, and on petroleum in particular. This issue has been ignored, if not forgotten, by all but a few analysts and policy makers during the last half of the 1980s, a period during which nominal crude oil prices declined from around $30 per barrel to $10 per barrel before increasing again to settle in the mid-to-high teens.

Not surprisingly, public interest in energy conservation and a national energy policy subsided as soon as oil prices declined into the low twenties and high teens. Indeed, the oil price most often faced by the consumers, motor gasoline, was essentially the same at mid-year 1991, when adjusted for inflation, as prior to the 1973-1974 price shock (see Figure 2).

Figure 2:

NOMINAL AND PRICE ADJUSTED RETAIL PRICE FOR LEADED GASOLINE (1970 TO MID-1991)



Source: U.S. Department of Commerce. The constant price series uses the CPI less energy as the deflator..

Public officials' disinclination towards serious energy conservation measures is illustrated by Congressional response to an Administration proposal of a 12 cent per gallon gas tax as part of the 1990 tax bill. The Congress enacted a 5 cent per gallon increase in the gasoline tax, an increase motivated more by the desire to increase revenue than to promote conservation.[1] The Iraq and Kuwait episode illustrates the fact that the stability of the world oil market is fragile. That fragility grows out of at least two factors: 1) the dependence of the world's economies on petroleum as an energy source and 2) the mismatch between petroleum producers and consumers.[2]

In the United States, in particular, discussion about energy and oil usage focused on how dependent the economy is on oil and how inefficient the U.S. economy is in its use of energy and oil.

This raises the issue of what it means to say that a country is dependent on oil, or on energy in general. In fact, there are a number of different ways to measure how dependent a country is on energy in general, or on a particular energy source such as oil. In this article two measures of energy dependence are discussed--total requirements and per capita requirements--and compare the dependence of the six heaviest users of energy (Canada, France, West Germany, Japan, the United Kingdom, and the United States) according to these measures. Investigation into the sources of dependence requires a discussion of energy efficiency. Again, there are different ways to measure a country's energy efficiency. Four measures of efficiency are presented and compared for the six countries according to each measure of efficiency. Finally, in order to explain some of the differences in efficiency across countries, efficiency by economic sector is examined. The next section deals with a discussion of dependence on energy in general, and on the major energy sources in particular.

AN OVERVIEW OF ENERGY DEPENDENCE

The primary energy sources available to an economy are: 1) coal, 2) petroleum and petroleum products, 3) natural gas, 4) nuclear energy, 5) hydro-electric, geothermal, and solar energy (H-G-S), 6) solid fuels other than coal (for example, wood, peat, and incinerated garbage), 7) electricity (normally electricity is a derived or secondary energy form, however, some countries import electricity, in which case it then becomes a primary energy source to those countries), and 8) heat derived from public combined heat and power plants.[3] In the aggregate the last three categories are of minor importance, or, as in the case for the other solid fuels category, the data are inadequate, therefore these categories are not considered in the analysis.

An economy's overall dependence on energy or on a particular energy source, for example, petroleum, can be measured in several ways. This article specifically examines total energy utilized from all sources by the economy; energy requirements relative to population (for example, per capita energy requirements from all sources or per capita energy requirements derived from oil); and energy use by source (for example, oil) as a proportion of an economy's total energy requirements.

Table 1: Total primary energy requirements by country
(millions of ton oil equivalent)

Year	U.S.	Japan	Germany	U.K.	France	Canada
1970	1,579	268	237	208	155	154
1972	1,695	299	249	213	170	171
1974	1,721	335	258	212	179	184
1976	1,778	328	262	205	180	199
1978	1,900	347	272	209	191	211
1980	1,826	355	274	201	198	223
1982	1,707	337	252	193	187	213
1984	1,782	364	262	192	195	224
1986	1,793	369	270	205	204	233
1988	1,928	399	274	209	209	250

Source: OECD.

Energy consumption varies widely across economies. Table 1 presents total primary energy requirements (TPER) for the years 1970 through 1988 for the world's six heaviest energy users: Canada, France, West Germany, Japan, the United Kingdom, and the United States (see note 3 for an explanation of the source and makeup of these data, and a definition of total primary energy requirements). According to Table 1, as of 1988, the U.S. was by far the largest user of energy. With total energy requirements of 1,928 million tons of oil equivalent (Mtoe--see note 3 for a definition of Mtoe) U.S. requirements were nearly five times that utilized by the next largest user (Japan) and nine times that of the smallest users, France and the U.K. At the same time, the rate of increase for the U.S. compared favorably with that of the other 5 countries. Indeed, in 1988, U.S. TPER were only 1.5 percent above 1978 levels.[4] Only in the U.K. and Germany was the growth in TPER lower.

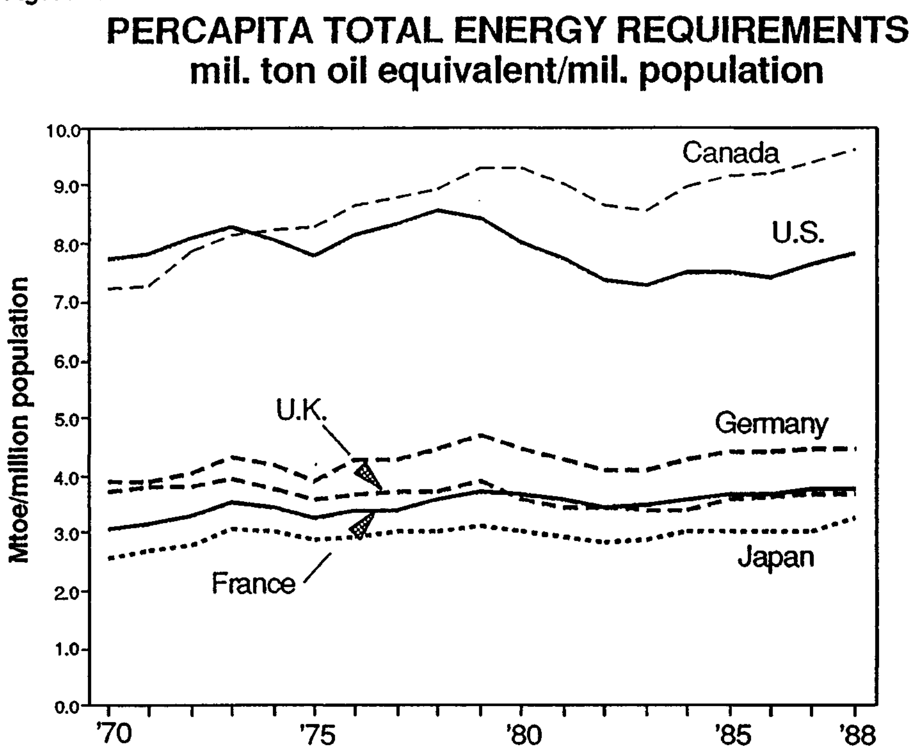
TPER falls short as a measure for comparing the relative energy dependence of different countries because it does not take into account factors which determine energy dependence, such as population, the size of the economy, the geographical size of the country, the type of goods produced, and the preferences and consumption habits of the population. For example, a country with a large population may have greater total energy requirements than a country with a small population without necessarily being more energy dependent, if per capita energy requirements are the same in both countries. A geographically large country that relies heavily on automotive transportation may be more energy dependent than a small country where the automobile is a lesser factor. Issues of economic size, population, geographic size, industrial composition and consumptions habits are addressed in more detail in the balance of the article. A consideration of per capita energy requirements for the six countries follows.

Table 2: Total primary energy requirements per capita
(million tons oil equivalent/million population)

Year	U.S.	Japan	Germany	U.K.	France	Canada
1970	7.7	2.6	3.9	3.7	3.1	7.2
1972	8.1	2.8	4.0	3.8	3.3	7.9
1974	8.1	3.0	4.2	3.8	3.4	8.2
1976	8.2	2.9	4.3	3.7	3.4	8.6
1978	8.5	3.0	4.4	3.7	3.6	9.0
1980	8.0	3.0	4.5	3.6	3.7	9.3
1982	7.3	2.8	4.1	3.4	3.4	8.6
1984	7.5	3.0	4.3	3.4	3.6	9.0
1986	7.4	3.0	4.4	3.6	3.7	9.2
1988	7.8	3.3	4.5	3.7	3.7	9.6

Per capita measures of total primary energy requirements are presented in Table 2 and Figure 3. They contrast sharply with the total requirements data in Table 1. U.S. per capita requirements for all energy remain high in comparison with those of Japan and the European countries but are substantially lower than for Canada. Most telling,changes over time as derived from the data in Table 2 indicate that the increase in per capita energy dependence in the U.S. during the 1970-1988 period compared favorably with the other countries. In 1988, U.S. per capita dependence for all energy increased less than 2 percent as compared with 29 percent for Canada, 23 percent for Japan, 20 percent for France, and 14 percent for Germany. Per capitarequirements declined 2 percent in the U.K.

Figure 3:



Source: Derived from OECD.

Even more favorable is the per capita energy requirement performance of the U.S. during the last ten years of the period. By this measure the U.S. joined the U.K. in reducing its per capita overall energy dependence while energy dependence elsewhere continued to rise.

The following section addresses the issue of energy dependence by energy source.

Petroleum

Before discussing the specific measures of oil dependence it is important to distinguish between an economy's overall dependence on petroleum and an economy's import dependence on petroleum. For example, a country may use little oil and produce none domestically, consequently importing all oil used. Such a country would have a low total dependence on petroleum but a high import dependence. Alternatively, an oil-rich country that has a high level of oil utilization may be a net exporter of petroleum. This country would have a high total dependence but no dependence on imports. The press and policy makers are often interested in import dependence because it has important implications for a country's national security and its international balance of payments.[5] However, for the reasons just given, import dependence should not be confused with overall dependence. In this article attention is restricted to overall dependence. The issue of import dependence is not addressed.

Table 3: Primary energy requirements supplied by petroleum, by country
(millions of ton oil equivalent)

Year	U.S.	Japan	Germany	U.K.	France	Canada
1970	691	184	128	101	94	72
1972	771	219	140	111	114	78
1974	774	244	134	105	118	83
1976	824	232	139	92	116	89
1978	904	255	142	95	117	89
1980	792	235	131	82	111	89
1982	708	208	111	77	93	77
1984	724	214	111	88	86	72
1986	751	207	118	78	86	73
1988	791	226	116	79	86	79

Source: OECD.

As a group, the six countries increased their TPER supplied by oil from 1,270 Mtoe in 1970 to 1,377 Mtoe in 1988, an increase of 8 percent (refer to note 3 for definitions of TPER and Mtoe). The totals are derived from Table 3. Significantly, however, the absolute level of oil requirements in 1988 was down 11 percent from the average 1,540 Mtoe requirement during the peak period of 1978-1980. Further evidence indicating that dependence on oil declined is found in data presented in Tables 4 and 5. Here we see that in 1988 two measures of oil dependence, proportion of TPER supplied by oil and per capita oil requirements, respectively, were well below levels recorded during the high consumption period of the late 1970s.

The reduction in dependence on oil by the six countries combined, as compared with the late 1970s, is all the more interesting in the face of the increase in total primary energy requirements by these economies over the same period (see Table 1). Total energy requirements in the six countries combined increased 23 percent between 1970 and 1988 but only 4 percent during the latter half of the period--between 1978-1980 and 1988.

Table 4: Proportion of total energy requirements met by petroleum
(percent)

Year	U.S.	Japan	Germany	U.K.	France	Canada
1970	43.8	68.8	54.1	48.8	60.5	46.9
1972	45.5	73.2	56.2	52.1	66.7	45.7
1974	45.0	72.7	51.8	49.6	65.6	45.0
1976	46.3	70.6	53.0	45.0	64.4	44.6
1978	47.6	73.4	52.4	45.5	61.1	42.3
1980	43.4	66.1	47.9	40.9	56.0	39.9
1982	41.5	61.7	44.3	39.9	49.6	36.1
1984	40.6	58.9	42.5	45.9	44.3	32.3
1986	41.9	56.2	43.8	37.7	42.1	31.4
1988	41.0	56.6	42.5	38.1	41.2	31.5

In an examination of the individual country data presented in Table 4, two patterns stand out. First, in each of the six countries, petroleum accounts for a major but declining proportion of total energy requirements. Second, throughout most of the 19 year period, oil accounted for a substantially smaller proportion of TPER in the United States than elsewhere--except Canada and to a lesser extent the U.K. At the same time, however, the decline in oil's proportional contribution to total energy requirements was markedly smaller in the United States than elsewhere.

As shown in Table 4, in 1970 the proportion of total energy requirements supplied by petroleum ranged from a low of 44 percent in the United States to a high of 69 percent in Japan. Eighteen years later the proportion of total energy requirements provided by oil was substantially reduced, ranging from a low of 32 percent in Canada to a high of 57 percent in Japan.

Indeed, the absolute dependence on petroleum, that is, the total amount of oil utilized by the economy, declined for three of the countries between 1970 and 1988: France, Germany, and the U.K. (see Table 3). In all six countries the TPERs supplied by oil were lower in 1988 than during the peak oil-use years of the late 1970s; ranging from down 13 percent for the U.S. to down 37 percent for France.

This reduction in the proportion of TPER supplied by oil and/or the reduction in the absolute contribution of oil to TPER occurred in the face of a continued expansion in overall energy requirements in these economies--with the exception of the United Kingdom, where TPER from all sources remained stable (see Table 1).

During the 1970-1988 period, less than half of U.S. energy requirements (ranging from 48 percent in 1978 down to 41 percent in 1988) were derived from oil, while in Japan well over half (ranging from 73 percent in 1972 to 57 percent in 1988) of energy requirements were supplied by oil (see Table 4).[6]

During much of the 1970s, the proportion of total energy requirements supplied by oil in Canada, France, Germany, and the U.K. generally fell within the range circumscribed by the U.S. and Japan. During the late 1980s, however, the relative degree of reliance on oil as an energy source by these countries declined so that their use of oil as a proportion of total energy requirements became nearly equal to or, in some cases, less than that of the United States. Thus, while the United States compared favorably in oil usage as a proportion of total energy requirements at the outset of the period, its economy did not progress as rapidly toward the replacement of oil with other sources of energy within the overall energy requirements composite as did the others.

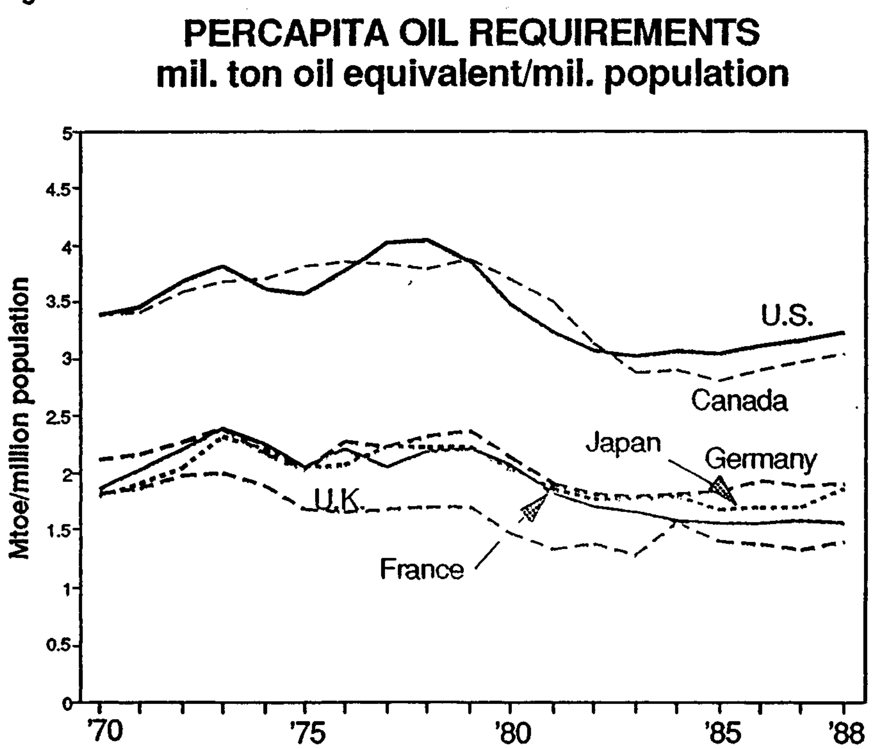
The per capita measure of oil dependence presents a rather different perspective. Per capita oil requirements, as shown in Table 5 and Figure 4, split the six countries into two packs. According to this measure, Canada and the United States appear as high oil dependent economies, as they did for total per capita energy requirements. Per capita oil requirements in the U.S. and Canada in 1988 (3.2 Mtoe/million population and 3.0 Mtoe/MP) were double that of France and the U.K. and were more than 50 percent larger than the per capita measures of 1.8 and 1.9 Mtoe/MP in Japan and Germany.

Table 5: Primary energy requirements supplied by petroleum per capita
(million tons oil equivalent/million population)

Year	U.S.	Japan	Germany	U.K.	France	Canada
1970	3.4	1.8	2.1	1.8	1.9	3.4
1972	3.7	2.0	2.3	2.0	2.2	3.6
1974	3.6	2.2	2.2	1.9	2.2	3.7
1976	3.8	2.1	2.3	1.6	2.2	3.9
1978	4.1	2.2	2.3	1.7	2.2	3.8
1980	3.5	2.0	2.1	1.5	2.1	3.7
1982	3.1	1.8	1.8	1.4	1.7	3.1
1984	3.1	1.8	1.8	1.6	1.6	2.9
1986	3.1	1.7	1.9	1.4	1.6	2.9
1988	3.2	1.8	1.9	1.4	1.5	3.0

In sum, the per capita measure of oil dependence gives a somewhat different picture than does the measure of oil requirements as a proportion of total energy requirements. The proportional measure suggests that the dependence on oil relative to all energy sources is comparatively low for Canada, France, and the U.K. The relative oil dependence of the U.S., according to this measure, is in the middle of the six countries, and is especially high for Japan.

Figure 4:



Source: Derived from OECD.

However, the per capita measure indicates that the U.S. and Canada experience a comparatively high level of dependence on petroleum; substantially lower dependence levels are recorded in the other four countries. As discussed in more detail later these high dependence levels for the U.S. and Canada are in part linked to their dependence on transportation and the related large geographical size of the countries. There is a common thread through both measures across countries, however. Dependence on oil, especially since the late 1970s, has declined.

The above discussion implies several conclusions for the issue of petroleum dependence. First, the response of the U.S. economy to the oil price shocks in the post 1973 period appears weaker than elsewhere. During the 1970-1973 period the U.S. economy relied proportionately less on petroleum to meet its total energy needs than did any of the other five countries. In the aggregate, U.S. oil use accounted for 44 percent of U.S. energy requirements, well below an average (weighted by TPER by country) of 52 percent for the other five.

By 1988, oil's share of total U.S. energy requirements had declined, but by only 3 percentage points, to 41 percent. The weighted average oil share of total energy requirements for the other five countries declined 8 percentage points, but at 44 percent remained above the U.S. figure, primarily as a result of the influence of Japan's continued heavy relative dependence on oil. However, in an absolute sense, that is, in terms of quantity of energy consumed, the U.S. and Canadian economies are heavily dependent on energy in total and on petroleum in particular. Per capita requirements for these two countries are consistently well above those for the other countries. The reduction in their dependence levels has been substantial, but they have a long way to go to attain levels comparable with the other countries. Indeed, the geographical size and the related dependence on transportation of the U.S. and Canada could effectively set lower limits on their dependence levels that are well above those of the other four countries.

OTHER ENERGY SOURCES

Apart from petroleum there are two other major hydro-carbon energy categories (coal and natural gas) and two nonhydrocarbon energy categories (nuclear and an agglomeration of hydroelectric-geothermal-solar) that constitute the remainder of primary energy sources for these economies. Given some reasonable adjustment period and favorable relative prices, these energy sources are potential substitutes for petroleum products in numerous industrial and power generation uses. The marginal cost of these other primary energy sources rose less rapidly than for petroleum during the decade following the initial 1973-1974 OPEC oil price shock. (In the U.S. this was partially due to government regulation.) Consequently, it is not surprising that over the period examined there was a relative movement away from oil utilization toward the alternatives. However, within this general pattern, there were substantial differences between countries and between energy forms.

Coal

During much of the 1970-1988 period, coal ranked second to oil as an energy source in the three European countries and Japan. Coal utilization for the six countries in total, like that for oil, increased during 1970-1988 while at the same time coal's relative importance as an energy source declined. However, the aggregated figures mask important individual country diversions from the overall trend.

Total energy requirements derived from coal declined in France, Germany, and the U.K. during the 1970-1988 period (see Table 6). As coal is primarily a power source for the generation of electricity, it is not surprising that the decline in coal energy requirements appears to parallel the increased use in these economies of natural gas and nuclear power.

Table 6: Primary energy requirements supplied by coal, by country
(million tons oil equivalent)

Year	U.S.	Japan	Germany	U.K.	France	Canada
1970	291.4	61.6	89.8	88.7	37.1	17.1
1972	289.4	54.7	81.5	70.7	29.4	16.5
1974	312.1	61.5	84.6	68.1	29.5	14.9
1976	341.3	56.6	77.9	70.2	30.1	16.8
1978	356.8	46.6	74.5	67.3	30.1	18.0
1980	376.2	59.6	83.0	68.8	32.9	21.2
1982	370.5	64.3	81.8	64.0	29.9	23.0
1984	412.1	69.6	82.8	46.8	25.8	26.7
1986	416.2	69.0	77.5	65.6	20.7	23.9
1988	454.1	73.6	74.2	66.0	19.3	27.5

Source: OECD.

Table 7: Proportion of total energy requirements met by coal
(percent)

Year	U.S.	Japan	Germany	U.K.	France	Canada
1970	18.5	23.0	37.9	42.7	23.9	11.1
1972	17.1	18.3	32.7	33.3	17.3	9.6
1974	18.1	18.4	32.8	32.1	16.5	8.1
1976	19.2	17.2	29.7	34.2	16.7	8.4
1978	18.8	13.4	27.4	32.3	15.8	8.5
1980	20.6	16.8	30.3	34.3	16.6	9.5
1982	21.7	19.1	32.5	33.2	16.0	10.8
1984	23.1	19.1	31.6	24.4	13.2	11.9
1986	23.2	18.7	28.7	31.9	10.1	10.3
1988	23.5	18.5	27.1	31.7	9.2	11.0

Coal remained an important energy source in Germany and the U.K., accounting for around 30 percent of their total energy requirements in 1988. Along with the absolute decline in coal use in France, Germany, and the U.K., the relative importance of coal as an energy source also declined (see Table 7).

In the U.S., Japan, and Canada, coal use increased progressively during the 1970-1988 period. In Canada, coal was relatively less important as an energy source than in the European or Japanese economies. During the 19 year span, coal utilization increased apace with the increase in the economy's total energy requirements. Thus, in Canada, coal maintained a rather stable though comparatively low level share of total energy requirements--ranging between 9 percent and 11 percent of the total.

Coal's role as an energy source in the United States moved counter to the trend elsewhere. Indeed, coal was the only major hydrocarbon-based fuel to record an increased proportional contribution to U.S. energy requirements during the period--increasing from 19 percent to 24 percent of total energy requirements.

Table 8: Primary energy requirements supplied by coal per capita
(millions of ton oil equivalent/million population)

Year	U.S.	Japan	Germany	U.K.	France	Canada
1970	1.42	0.59	1.48	1.59	0.73	0.80
1972	1.38	0.51	1.32	1.26	0.57	0.75
1974	1.46	0.56	1.36	1.21	0.56	0.66
1976	1.57	0.50	1.27	1.25	0.57	0.73
1978	1.60	0.41	1.21	1.2	0.56	0.76
1980	1.65	0.51	1.35	1.22	0.61	0.88
1982	1.59	0.54	1.33	1.14	0.55	0.93
1984	1.74	0.58	1.35	0.83	0.47	1.07
1986	1.72	0.57	1.27	1.16	0.37	0.94
1988	1.84	0.60	1.21	1.16	0.35	1.06

On a per capita basis, energy requirements supplied by coal increased during 1970-1988 in Canada and the United States, remained stable in Japan, and declined elsewhere (see Table 8). As an absolute measure, U.S. per capita dependence on coal remains well above that of any of the other countries--1.8 Mtoe/MP as compared with 1.2 Mtoe/MP in Germany, the second largest per capita dependent user of coal.

In sum, by 1988, coal still retained its position as the second largest energy source in Germany, Japan, and the U.K., and became the second largest source of energy for the U.S.

Natural gas

With the exception of the United States and Canada, natural gas was a distinctly minor factor in the overall energy package during the early 1970s (see Table 9). This probably was due, in large part, to the lack of known indigenous supplies and the lack of adequate transport facilities. As shown in Table 10, prior to the oil crisis of 1973-1974, natural gas accounted for 30 percent and 20 percent of total energy requirements in the U.S. and Canada, respectively.

Table 9: Primary energy requirements supplied by natural gas, by country
(million tons oil equivalent)

Year	U.S.	Japan	Germany	U.K.	France	Canada
1970	499.2	3.1	11.8	10.2	8.2	29.2
1972	522.0	3.4	20.4	23.3	11.5	35.0
1974	499.2	6.7	31.5	30.0	14.1	37.0
1976	459.0	9.8	35.4	33.5	16.9	38.5
1978	459.7	15.8	41.3	36.9	18.8	40.8
1980	477.0	21.5	44.0	40.3	21.6	43.2
1982	430.4	22.7	37.6	40.7	21.1	42.4
1984	422.7	32.5	40.7	43.5	23.7	45.2
1986	388.5	35.5	41.0	47.2	24.3	46.8
1988	429.0	37.7	44.4	46.2	23.8	51.8

Source: OECD.

Table 10: Proportion of total energy requirements met by natural gas
(percent)

Year	U.S.	Japan	Germany	U.K.	France	Canada
1970	31.6	1.1	5.0	4.9	5.3	19.0
1972	30.8	1.2	8.2	11.0	6.8	20.5
1974	29.0	2.0	12.2	14.2	7.9	20.1
1976	25.8	3.0	13.5	16.3	9.4	19.4
1978	24.2	4.5	15.2	17.7	9.9	19.3
1980	26.1	6.1	16.1	20.1	10.9	19.3
1982	25.2	6.7	14.9	21.1	11.3	19.9
1984	23.7	8.9	15.6	22.7	12.1	20.2
1986	21.7	9.6	15.2	23.0	11.9	20.1
1988	22.2	9.4	16.2	22.2	11.4	20.8

Elsewhere, the natural gas contribution to total energy requirements of the respective economies ranged from 1 percent in Japan to 5 percent in France and Germany. Increases in the importance of natural gas-derived energy from the mid-1970s to mid-1980s were substantial, in total volume as well as proportional terms. This was possible because supplies were made more plentiful in Europe by the opening of natural gas pipelines from the U.S.S.R. and the development of economically viable ocean going natural gas tankers during the 1970s. During the same period, natural gas use nearly doubled in Canada (see Table 9), approximately keeping pace with total energy requirements. As a result, only marginal gains in the relative contribution of natural gas to total energy requirements occurred in Canada. In the U.S., natural gas use declined between 1970 and 1988, with a consequent sharp drop in the relative contribution of this energy form to total energy requirements.

Table 11: Primary energy requirements supplied by natural gas per capita
(millions of ton oil equivalent/million population)

Year	U.S.	Japan	Germany	U.K.	France	Canada
1970	2.43	0.03	0.19	0.18	0.16	1.37
1972	2.49	0.03	0.33	0.42	0.22	1.61
1974	2.33	0.06	0.51	0.53	0.27	1.65
1976	2.11	0.09	0.58	0.60	0.32	1.67
1978	2.07	0.14	0.67	0.66	0.35	1.73
1980	2.09	0.18	0.71	0.72	0.40	1.79
1982	1.85	0.19	0.61	0.72	0.39	1.72
1984	1.78	0.27	0.67	0.77	0.43	1.81
1986	1.61	0.29	0.67	0.83	0.44	1.85
1988	1.74	0.31	0.72	0.81	0.43	2.00

Per capita dependence on natural gas increased in all countries but the U.S., where it declined by 33 percent between 1970 and 1988 (see Table 11). Still, by comparison, the U.S. was remained relatively more dependent on natural gas. Only in 1984 did Canada surpass the U.S. as a country more per capita dependent on natural gas. In 1988, Canada's dependence level on natural gas stood at 2 Mtoe/MP. The United States followed with a dependence level of 1.7 Mtoe/MP. Of the six countries, Japan recorded the lowest dependence level with per capita requirements of 0.3 Mtoe.

Nuclear power

Nuclear energy is the only primary energy source to record a common pattern across countries over the time frame examined. In each country, nuclear power recorded multiple gains during the 1970-1988 period, regardless of measure (see Tables 12, 13, and 14).

Table 12: Primary energy requirements supplied by nuclear power, by country
(million tons oil equivalent)

Year	U.S.	Japan	Germany	U.K.	France	Canada
1970	5.2	1.1	1.4	5.8	1.3	0.2
1972	12.9	2.3	2.0	6.6	3.3	1.6
1974	27.1	4.8	2.7	7.5	3.3	3.3
1976	45.3	8.4	5.4	8.1	3.5	3.9
1978	65.5	14.5	8.0	8.3	6.8	7.0
1980	59.5	20.2	9.8	8.3	13.7	8.5
1982	67.0	25.1	14.2	9.8	24.3	8.6
1984	77.6	32.9	20.7	12.1	42.7	11.7
1986	98.0	37.6	26.7	13.2	56.8	15.9
1988	124.8	39.9	32.4	14.2	61.5	18.5

Source: OECD.

The most dramatic of the increases was in France, where the nuclear power contribution to total energy requirements rose from less than 1 percent in 1970 to 30 percent in 1988 (see

Table 13). The gain in the nuclear share of total energy requirements in the other countries was less dramatic but nonetheless substantial. Except for the U.K., where nuclear power accounted for nearly 3 percent of total energy requirements in 1970, nuclear power generally accounted for less than 1 percent of total energy requirements in 1970. Apart from France, by 1988 nuclear power's contribution to total energy requirements ranged from less than 7 percent in the U.S. to 12 percent in Germany.

Table 13: Proportion of total energy requirements met by nuclear energy
(percent)

Year	U.S.	Japan	Germany	U.K.	France	Canada
1970	0.3	0.4	0.6	2.8	0.8	0.1
1972	0.8	0.8	0.8	3.1	1.9	0.9
1974	1.6	1.4	1.1	3.5	1.8	1.8
1976	2.5	2.5	2.1	3.9	2.0	2.0
1978	3.4	4.2	3.0	4.0	3.6	3.3
1980	3.3	5.7	3.6	4.1	6.9	3.8
1982	3.9	7.4	5.6	5.1	13.0	4.0
1984	4.4	9.0	7.9	6.3	21.9	5.2
1986	5.5	10.2	9.9	6.4	27.8	6.8
1988	6.5	10.0	11.8	6.8	29.5	7.4

Table 14: Primary energy requirements supplied by nuclear power per capita
(millions of ton oil equivalent/million population)

Year	U.S.	Japan	Germany	U.K.	France	Canada
1970	0.03	0.01	0.02	0.10	0.03	0.01
1972	0.06	0.02	0.03	0.12	0.06	0.07
1974	0.13	0.04	0.04	0.13	0.06	0.15
1976	0.21	0.07	0.09	0.14	0.07	0.17
1978	0.29	0.13	0.13	0.15	0.13	0.30
1980	0.26	0.17	0.16	0.15	0.25	0.35
1982	0.29	0.21	0.23	0.17	0.45	0.35
1984	0.33	0.27	0.34	0.21	0.78	0.47
1986	0.41	0.31	0.44	0.23	1.02	0.63
1988	0.51	0.33	0.53	0.25	1.10	0.71

On a per capita basis, France also appears to be relatively dependent on nuclear energy (see Table 14). In 1988 it recorded the highest per capita dependence on nuclear power, at 1.1 Mtoe/MP. Canada, at 0.7 Mtoe/MP, and Germany, at 0.5 Mtoe/MP ranked well behind France in both per capita and relative dependence. The U.S., the U.K., and Japan round out the list in terms of their dependence on nuclear power.

Hydroelectric-geothermal-solar (H-G-S) power

A country's utilization of H-G-S energy is more heavily dependent on the natural resource base of the country than are the other energy forms. Within this category, hydroelectric energy was among the earliest energy forms harnessed. Despite new technologies utilized to extract geothermal and solar power, these energy sources have not yet made a widespread impact. For example, as of 1988, geothermal power is estimated to have accounted for less than 3 percent of U.S. total energy requirements.[7]

Table 15: Primary energy requirements supplied by hydroelectric-geothermal-solar energy, by country
(million tons oil equivalent)

Year	U.S.	Japan	Germany	U.K.	France	Canada
1970	56.1	19.6	4.0	1.3	12.8	35.4
1972	61.9	21.5	3.1	1.0	11.0	40.6
1974	68.5	20.8	4.0	1.1	12.7	47.1
1976	64.9	21.7	3.1	1.1	11.0	47.5
1978	64.0	18.4	4.1	1.2	15.5	52.6
1980	63.5	22.8	4.2	1.1	15.8	56.1
1982	70.9	20.9	4.4	1.3	16.1	57.6
1984	74.4	19.1	4.1	1.4	15.2	63.9
1986	68.1	19.5	4.1	1.6	14.6	69.4
1988	52.7	21.7	4.6	1.6	17.6	68.5

Source: OECD.

Table 16: Proportion of total energy requirements met by hydroelectric-geothermal-solar energy
(percent)

Year	U.S.	Japan	Germany	U.K.	France	Canada
1970	3.6	7.3	1.7	0.6	8.2	23.0
1972	3.7	7.2	1.2	0.5	6.5	23.7
1974	4.0	6.2	1.5	0.5	7.1	25.6
1976	3.6	6.6	1.2	0.6	6.1	23.9
1978	3.4	5.3	1.5	0.6	8.1	25.0
1980	3.5	6.4	1.5	0.6	8.0	25.1
1982	4.2	6.2	1.7	0.7	8.6	27.1
1984	4.2	5.3	1.6	0.7	7.8	28.6
1986	3.8	5.3	1.5	0.8	7.2	29.8
1988	2.7	5.4	1.7	0.7	8.4	27.4

As shown in Table 15, of the six countries examined, only two--Canada and France--recorded appreciable gains in the absolute level of energy derived from H-G-S. Only Canada, which in fact relies heavily on hydroelectric power, recorded an appreciable increase in the share of its total primary energy supplied by this source--from 23 percent of the total in 1970 to 27 percent in 1988 (see Table 16).

Canada's per capita dependence on H-G-S totaled 2.6 Mtoe/MP in 1988, 27 percent of its total energy requirements. Per capita dependence on H-G-S energy by the other countries was well below that of Canada (see Table 17). France ranked second with a dependence level of 0.3 Mtoe/MP, about 9 percent of its total energy requirements. Dependence levels for the remaining four countries were at 0.2 Mtoe/MP or lower. However, in Japan H-G-S energy accounted for about 6 percent of total energy.

Table 17: Primary energy requirements supplied by hydroelectric-geothermal-solar energy per capita
(millions of ton oil equivalent/million population)

Year	U.S.	Japan	Germany	U.K.	France	Canada
1970	0.27	0.19	0.07	0.02	0.25	1.66
1972	0.30	0.20	0.05	0.02	0.21	1.86
1974	0.32	0.19	0.06	0.02	0.24	2.10
1976	0.30	0.19	0.05	0.02	0.21	2.06
1978	0.29	0.16	0.07	0.02	0.29	2.23
1980	0.28	0.20	0.07	0.02	0.29	2.33
1982	0.31	0.18	0.07	0.02	0.29	2.34
1984	0.31	0.16	0.07	0.02	0.28	2.56
1986	0.28	0.16	0.07	0.03	0.26	2.74
1988	0.21	0.18	0.08	0.03	0.32	2.64

In summary, energy consumption and energy dependence vary widely across countries and by source of energy. Among the major industrial countries, the U.S., along with Canada, recorded levels of dependence on total energy that are comparatively high, as measured by per capita requirements. U.S. per capita requirements are on the order of twice those in Western Europe and Japan. At the same time, however, the rate of growth in U.S. per capita energy requirements was generally lower than elsewhere.

Dependence on oil in per capita terms for the U.S. and Canada also stands out. In Mtoe per million population, the U.S. and Canada's oil dependence are considerably higher than the next most dependent country, Germany. To some degree this is likely due to the large geographical area of these two countries and the importance transportation plays in their respective economic activity (this issue is discussed in more detail below). It is interesting to note that Japan, an economy that recorded the lowest per capita dependence on total energy of the six countries, was the only economy of the six that in 1988 recorded a per capita dependence on oil equal to 1970 levels (still only 1.8 Mtoe/MP) although by this measure its oil dependence had declined from the higher levels in the late 1970s.

Only Canada and France moved significantly away from hydrocarbon energy forms during the period examined. Both developed a strong reliance on nuclear and H-G-S energy forms while the other four countries remained heavily dependent on the various forms of hydrocarbon energy.

ENERGY EFFICIENCY

Energy is a ubiquitous factor-input in any industrial/consumption oriented economy. An understanding of how well or how efficiently energy is utilized in the output of any economy is a key variable in examining the energy environment. Efficiency in the utilization of energy inputs, and differentials in energy efficiency across countries, may explain in part why one economy is more dependent on energy, or on certain forms of energy, than is another economy. It should also be expected to be a significant factor contributing to the overall and relative productivity of the economies.

The concept of efficiency is based on the relationship between the physical inputs in production and the resulting level of physical product.[8] Measures of energy-use efficiency are easily enough derived where there are well defined inputs and outputs. Unfortunately, the physical product (output) of an economy is not so neatly defined. The closest such output measure is in the form of gross national product (GNP) or gross domestic product (GDP) adjusted for inflation to give real GNP:GDP.[9] Thus, given measures of aggregate energy inputs (total primary energy requirements) and economic output (real GDP) a technical efficiency measure can be defined as:

(1) $E_{i,t} = GDP_{i,t} / TPER_{i,t};$

where $E_{i,t}$ is the technical efficiency level for country *i*, at time *t*; $GDP_{i,t}$ is gross domestic product valued in billions of home currency at constant prices for country *i*, at time *t*; and TPER is total primary energy requirements in millions of ton oil equivalents (Mtoe) for country *i* at time *t*.

Technical efficiency is adequate for a within-country measure of "home country" efficiency, but is clearly meaningless for analysis of relative changes in cross-country efficiency or in an analysis of relative levels of efficiency across countries. One problem is that cross-country currency exchange value is not taken into account in measures of technical efficiency. For example, the $2.3 billion per million tons oil equivalent (Mtoe) technical energy efficiency for the U.S. in 1988 cannot be meaningfully compared with the DM7.2 billion/Mtoe level for Germany. Energy efficiency, in particular, output, must be measured in common units in order to compare countries. However, finding a common base to use in computing energy efficiency measures raises a new set of problems.

This article examines four efficiency measures, the results of which are described below.

Technical efficiency level (TEL), or home country efficiency, as described above, is a measure of the relationship between an economy's output (in price adjusted GDP, valued in terms of the home country currency) relative to the economy's energy input (all energy forms are converted to oil equivalents).

The *technical efficiency ratio (TER)* removes the units of measure (that is, value of home country GDP per quantity of oil equivalents used) from the technical efficiency level measure, and thus allows cross-country comparisons in terms of rates of change from some common base period. This ratio is derived from the index of a country's GDP divided by the index of its energy inputs. The base period is defined in the home country GDP index and the energy inputs index. Except where otherwise noted these indexes are set equal to 100 for the period 1970-1972. This measure suffers from the standard problems associated with indexes. In particular it is devoid of information about the level of efficiency (that is, the value of GDP output relative to the quantity of energy input) across countries. Further, it depends critically upon the countries' relative energy efficiency positions in the base year. The ratio reflects comparative developments in energy efficiency across countries as compared to their relative positions as of the base period. However, despite its shortcomings, this measure arguably provides the most meaningful basis for cross-country comparisons of energy efficiency.

Observed energy efficiency is obtained by converting TEL to a U.S. dollar base using annual average market exchange rates. This measure of efficiency is referred to as "observed" because it is based on an observed exchange rate. The observed rate is the market exchange rate that is typically, though not necessarily appropriately, used to convert various countries' outputs to a common currency base as a means to facilitate cross-country comparisons.

Purchasing power parity (PPP) energy efficiency is calculated by converting the TEL to a U.S. dollar base using PPP exchange rate-based estimates of GDP. Because PPP rates are based on the relative real purchasing power of currency units, a relationship that changes slowly, period-to-period movement in PPP exchange rates is far more constrained than that of market exchange rates. Consequently, PPP energy efficiency should be less volatile than that for observed energy efficiency.

The last two measures of energy efficiency represent an attempt to express levels of energy efficiency across countries. Such measures would be useful, for example, in the analysis of cross-country productivity. This article presents efficiency measures based on these formulations but the severity of the limitations inherent in such measures merits more than cursory examination. The discussion of that issue follows.

One of the problems with the observed efficiency measure is that the wide fluctuation in exchange rates during the past 20 years has exerted a profound influence on the measure of efficiency, an influence that does not reflect changes in the relative output or the relative welfare across the economies. For example, during the period examined, the annual average for the German mark/U.S. dollar exchange rate ranged from 3.65 DM/$ in 1970 to 1.76 DM/$ in 1988. During 1988, the DM/$ exchange rate ranged from a low of 1.57 DM/$ to a high of 1.90 DM/$. If no change whatsoever had occurred in relative technical efficiency between the U.S. and Germany, the change in exchange rates would have implied a reduction in the level of U.S. observed energy efficiency by more than 70 percent between 1970 and 1988. Prima facie, this is not a plausible conclusion. A decrease in the energy efficiency level of that magnitude implies a concurrent deterioration in U.S. welfare relative to Germany. There is no evidence that such a shift in relative welfare occurred.

Another possible approach is to use an exchange rate that provides a ratio of exchange between two currencies such that a specified value of either currency would purchase the same bundle of goods in either country. Economists refer to this construction as the purchasing power parity (PPP) exchange rate.

The OECD estimates that in 1988 the GDP purchasing power parity exchange rate between the German mark and the U.S. dollar was equivalent to 2.44 DM/$, as compared with the annual average DM1.76/$ market rate. From an economic perspective, a PPP exchange rate would appear to be the theoretically correct rate to use when converting economic output measures of foreign countries to common dollar base. Economists agree that market rate deviations from PPP should be expected because PPP is a long-run concept, while the market rate is short-term. Still, the last time the DM/$ exchange rate approached 2.44 DM/$ was in January 1986, when the rapidly depreciating dollar "passed through" on its way down from the exchange rate highs reached during the first quarter of 1985.

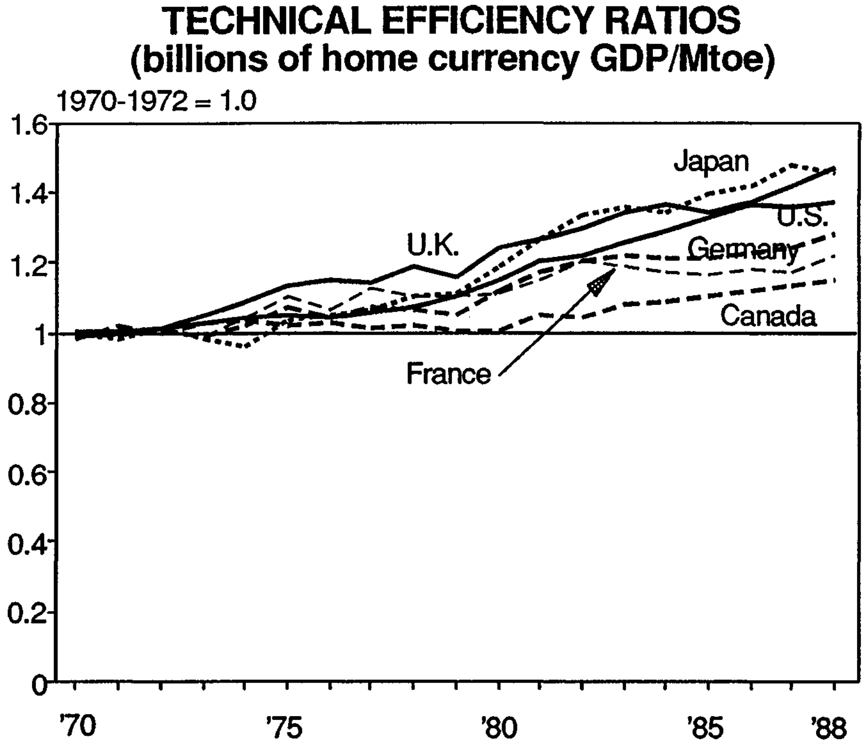
While it may be argued that the PPP rate is the theoretically correct rate over the long term, the market rate has seldom been even remotely in line with PPP rates. Market decisions are not based on PPP based exchange rates. A firm's management does not look at the international competitive ability of its firm in terms of PPP exchange rates. It seems a reasonable question then whether efficiency measures based on PPP conversions are any more economically meaningful than observed efficiency.[10]

Clearly, if levels of energy efficiency are a vital consideration, the analyst is faced with an unpleasant choice of tools. As will be seen, over the last decade, exchange rate movements have overwhelmed technical efficiency changes. While a discussion of efficiency levels follows it is not the intent here to focus undue attention on such measures. Their inclusion is intended primarily to illustrate the problems in developing a meaningful economic measure of oil efficiency levels.

Results

As shown in Table 18 and Figure 5, technical efficiency improved substantially in each of the six countries during the 1970-1988 period. Not surprisingly, most of the improvement occurred during the 1980s as changes in economic structures, prompted by the 1973-1974 and 1979-1980 oil price shocks, filtered through the economies. By 1988, technical efficiency gains in the six countries ranged from a low of 14 percent in Canada, relative to its 1970-1972 average, to a high of 39 percent in the U.K. Performance of the U.S. economy compared favorably with respect to the remaining countries; its technical efficiency ratio rose 31 percent from its 1970-1972 average--a more rapid gain than in France and Germany but slower than in Japan.

Figure 5:



Source: Derived from OECD.

Table 18 shows that observed efficiency varied broadly across countries and illustrates the dramatic influence of movements in exchange rates. As can be seen in Figure 6, the impact of the dollar appreciation during the 1980-1985 period and the subsequent depreciation during 1985-1987 is clearly outlined in the data. Canada is the exception, where exchange rate movements were less pronounced.

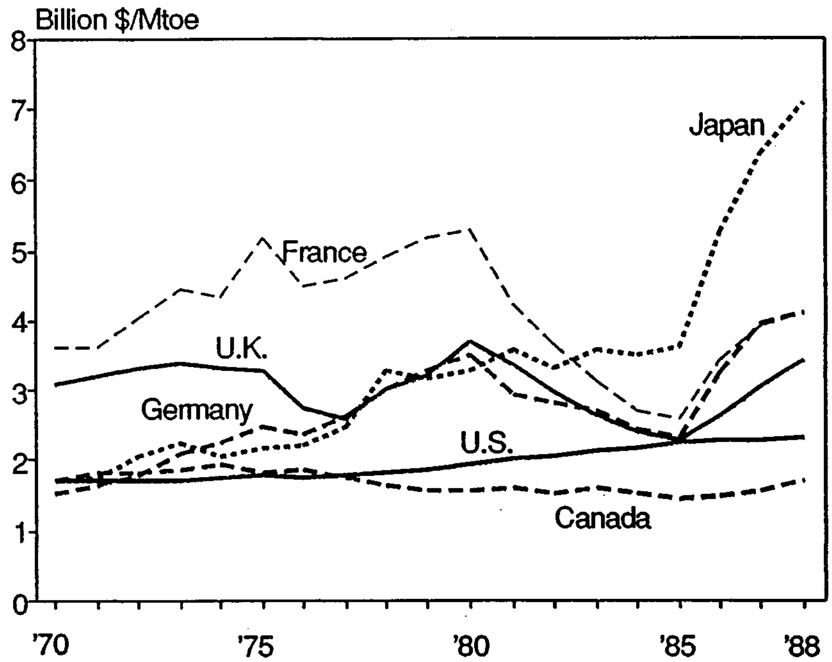
Table 18: Changes in energy efficiency
(efficiency levels in billion dollars/Mtoe)

	U.S.	Japan	Germany	U.K.	France	Canada
Technical efficiency						
Percent change (1970 to 1988)	31	38	24	39	20	14
Observed efficiency						
1970 (level)	1.70	1.73	1.54	3.10	3.61	1.71
1988 (level)	2.31	7.05	4.13	3.43	4.11	1.71
percent change	31	141	99	10	13	0
PPP efficiency						
1970 (level)	1.70	2.42	1.71	4.53	4.21	1.67
1988 (level)	2.31	4.35	2.97	3.18	3.27	1.67
percent change	31	59	55	-35	-25	0

Observed efficiency levels in four of the countries (Canada, Germany, Japan, and the U.S.) began the period in relatively close proximity--$1.5 to $1.75 billion GDP/Mtoe. On the other hand, the French and the U.K. economies recorded substantially higher observed efficiency levels in 1970; $3-$3.5 billion GDP/Mtoe. By 1988, observed efficiency levels for the six countries diverged broadly, ranging from $1.7 billion/Mtoe for Canada and $2.3 billion/Mtoe for the U.S. to $7.1 billion/Mtoe for Japan.

Figure 6:

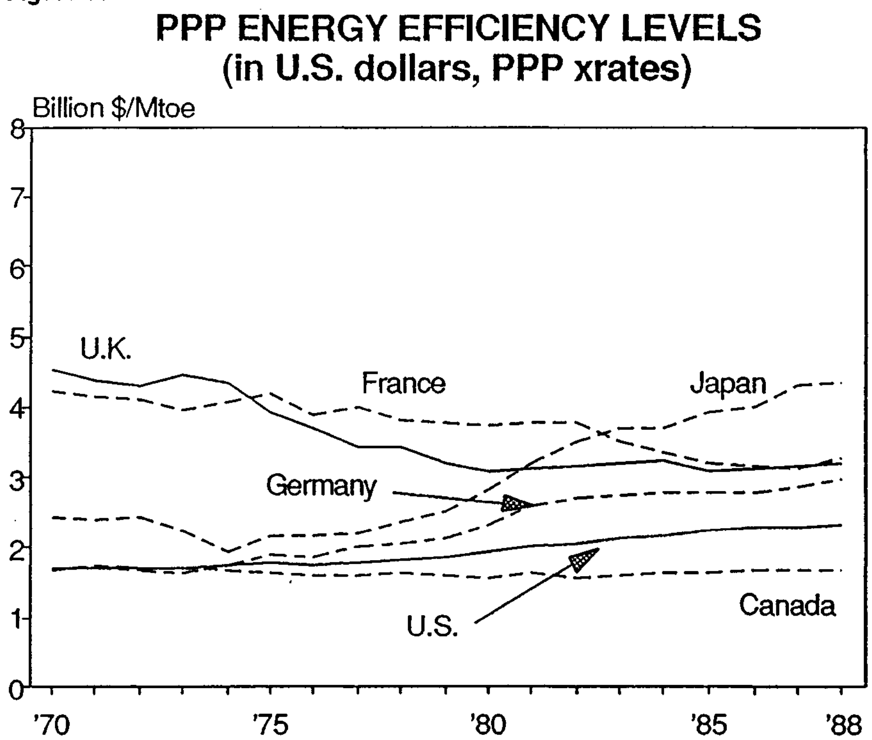
OBSERVED ENERGY EFFICIENCY LEVELS (in U.S. dollars, prevailing xrates)



Source: Derived from OECD.

As expected, PPP efficiency levels show change over time that is considerably less dramatic than the fluctuations recorded in the observed efficiency measure (see Figure 7 and Table 18).[11] The level of energy efficiency for the U.S. remained well below that of the other countries (except Canada) during most of the period. The rate of gain in U.S. energy efficiency based on PPP compares favorably with Canada, France, and the U.K. and lagged behind that of Germany and Japan, though not so severely as when the common valuation measure of output was based on the prevailing exchange rates. Indeed, the most dramatic development coming out of the PPP based data is the deterioration in energy efficiency levels in France and the U.K.

Figure 7:



Source: Derived from OECD.

Energy efficiency by economic sector

Here to fore the discussion has focused on energy utilization by whole economies. Different sectors of an economy might be expected to be more or less dependent on energy and more or less efficient in their use of energy. Large efficiency gains in certain sectors might be expected to positively influence the competitiveness of those sectors relative to other sectors, or relative to similar sectors in other countries. The limited data available suggest, not surprisingly, that efficiency differentials exist across sectors of an economy as well as across countries.

This article focuses upon two different types of comparison. First, it looks at two broad economic sectors defined as "industrial" and "nonindustrial." The second comparison examines a sector classification defined by "all transportation" and "nontransportation."

The industrial/nonindustrial sector analysis examines three countries--Germany, Japan, and the United States--for the period 1974-1988. The industrial sector includes a broad aggregation of manufacturing, construction, and mining and quarrying. The nonindustrial sector includes all other sectors of the economy. This particular sector and country breakdown is used to facilitate the construction of efficiency measures, as GDP (output) and energy consumption (input) data are available by these aggregate economic sectors.

Efficiency measures are calculated as the ratio of the dollar value of gross domestic product generated by industrial and nonindustrial sectors to total energy consumption by these two sectors. As in the earlier discussion, comparisons are based on measures of technical efficiency levels (TELs) and dollar output measures using prevailing exchange rates and PPP exchange rates, which yield measures of observed energy efficiency and PPP energy efficiency, respectively.

Within countries, GDP output by sector, valued in the homecurrency relative to units of energy consumed by the sector, indicate an interesting diversity in efficiency trends. It was expected that TELs (the technical efficiency level) would be higher in the industrial sector than in the nonindustrial sector. This pattern did indeed emerge, but did not hold universally.

In the United States the nonindustrial sector recorded a TEL of $1.8 billion/Mtoe, slightly higher but probably not significantly different from the $1.7 billion/Mtoe recorded for the industrial sector. By 1987, the TELs for both sectors were identical at $2.5 billion/Mtoe.

In Germany, the industrial sector began the period with a TEL of DM6.0 billion/Mtoe, well below the DM7.3 billion/Mtoe for the nonindustrial sector. However, rapid efficiency gains in industry during the late 1970s and early 1980s pushed Germany's industrial TEL to DM9.2 billion/Mtoe, substantially higher than the DM7.8 billion/Mtoe TEL for the nonindustrial sector.

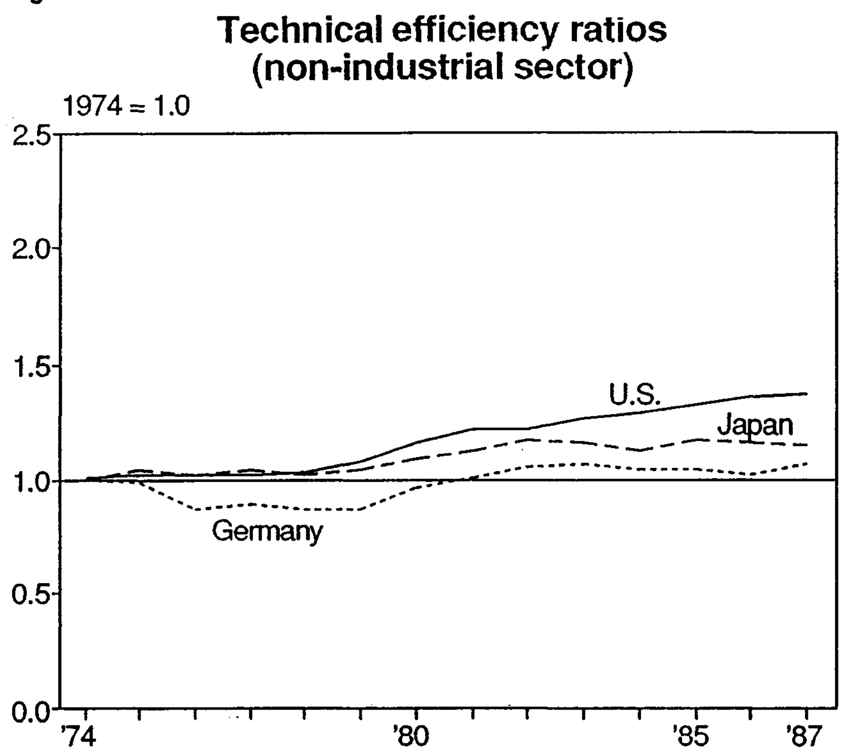
Among the most interesting developments were the relative sector levels and changes in technical efficiency derived from the Japanese data. In 1974, industry's TEL stood at Y493 billion/Mtoe, far lower than the nonindustrial Y1,106 billion/Mtoe. By 1987, nonindustrial TEL still remained above that of industry, but industry's dramatic increase in energy efficiency brought its TEL to Y1,092 billion/Mtoe compared with Y1,266 billion/Mtoe for the nonindustrial sector.

One result which met the expectation of higher industrial TELs in each of the three economies was the more rapid rates of gain in energy efficiency in the industrial sector as compared with the nonindustrial sector. The most rapid TEL gains in industry occurred in Japan, up 80 percent, and Germany, up 42 percent, as compared with a gain of 36 percent for U.S. industry. Higher energy costs could be expected to stimulate increased efficiency in that sector, relative to the nonindustrial sector. The industrial sectors in Japan and Germany account for a somewhat larger proportion of GDP, 42 and 36 percent respectively, in 1974 as well as in 1987, than in the United States where industry's proportion dropped from 33 percent in 1974 to 30 percent in 1987. It remains puzzling, however, as to why the industrial TELs in Germany and especially Japan compared poorly with nonindustrial TELs in the early 1970s.

Another interesting development is most easily seen in a graph of the technical efficiency ratio (TER). Recall that this ratio is the index of the home country GDP divided by the index of energy input. In this case the base period is 1974, the first year of the data set. Figures 8 and 9 show TERs for the industrial and nonindustrial sectors in the U.S., Japan, and Germany for the period 1974-1988. Figure 8 shows that in the nonindustrial sector the U.S.

performed relatively better than the economies of either Japan or Germany. U.S. technical efficiency in this sector rose 31 percent between 1974 and 1987 while nonindustrial energy efficiency in Japan and Germany rose 13 percent and 7 percent, respectively.

Figure 8:

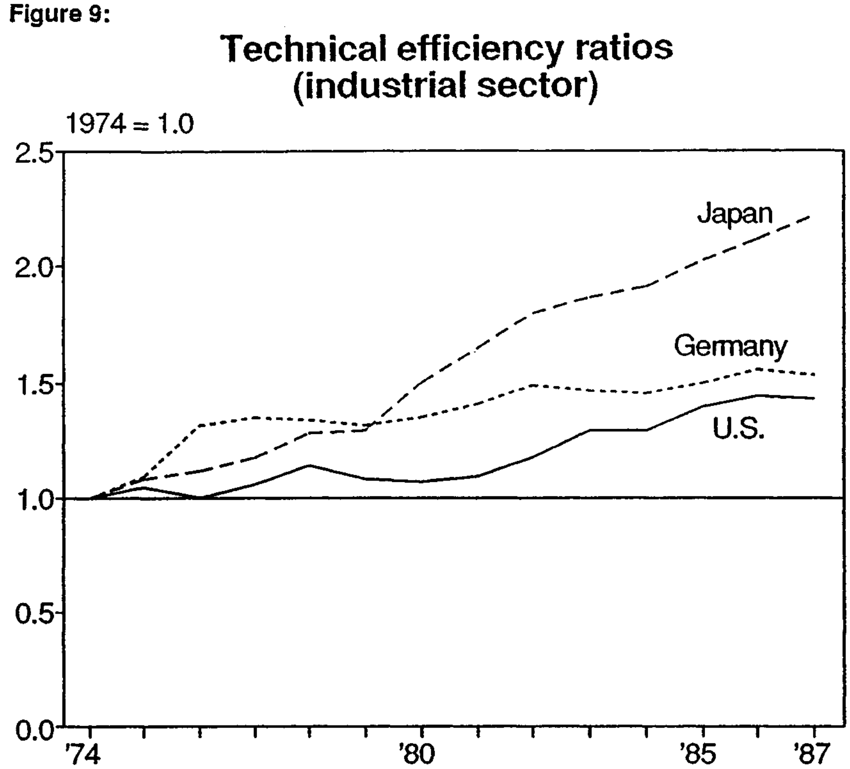


Source: Derived from OECD.

As shown in Figure 9, the TERs for the industrial sector indicates that in this case the U.S. did not fair so well relative to gains in Japan and Germany. The TER for U.S. industry rose 35 percent compared with 31 percent for the nonindustrial sector. The ratio's gain in Germany was somewhat greater (42 percent) and in Japan substantially greater (80 percent). The United States' overall TER, buoyed up by gains in the nonindustrial sector, showed a gain (up 32 percent) about midway between Japan (47 percent) and Germany (19 percent).

Measures of observed and PPP efficiency levels for the industrial and nonindustrial sectors were subject to the same dominating influences of exchange rate movements noted earlier. Throughout, the PPP based and observed efficiency levels for industrial and for nonindustrial sectors in Japan and Germany were well above efficiency levels in the United States, indicating prima facie that the U.S. lost ground in energy efficiency in the industrial sector as well as in nonindustrial sector. However, two-thirds of the gain in observed energy efficiency in Japan's industrial category and nine-tenths of the gain in its nonindustrial category, for example, were due to changes in market exchange rates. Exchange rate movements had a similar effect on Germany's observed efficiency measures for industrial and nonindustrial sectors. Once again, exchange rate movements dominate the data.

Figure 9:



Source: Derived from OECD.

Table 19: Selected demographic characteristics, 1988

	U.S.	Japan	Germany	U.K.	France	Canada
Geographic area, (000) sq. mi.	3,615.1	144.0	96.0	94.2	212.8	3,851.8
Population, millions	246.3	122.6	61.4	57.1	55.9	26.0
Population density per sq. mi.	68.1	851.5	639.5	606.0	262.5	6.7

Source: OECD and Worldmark.

As noted earlier, a country's physical size and the dispersion of its population may affect energy efficiency. In particular, one would expect a country with a comparatively high level of economic activity in a small geographic area to have a comparatively high level of energy efficiency, due to lower energy expended on transportation. That is, countries with greater population densities should be more energy efficient, other things being equal. As shown in Table 19, the U.S. and Canada have substantially smaller population density per square mile than the other countries in the sample. This may explain in part why the U.S. and Canada fair relatively poorly on energy efficiency measures compared to the other countries. In order to investigate this hypothesis, we examine the development of energy efficiency in the transportation vs. nontransportation sectors over the 1970-1988 period.

Two formulations of the data are examined: Both are modifications of previously discussed measures--technical efficiency and the per capita utilization measure used above in the energy dependence section. This analysis relies on OECD data that facilitate a breakdown of energy consumption by source of energy into total transportation and nontransportation sectors.[12] Because transportation relies primarily on oil, rather than all energy, oil is used as the energy source measure. The reader should be aware that the data limitations cited in note 11 mean that the technical efficiency measures constructed here are not comparable with those constructed in earlier sections of the paper.

Table 20: Technical energy efficiency ratio for the transportation sector
(1970-1972 average = 1.0)

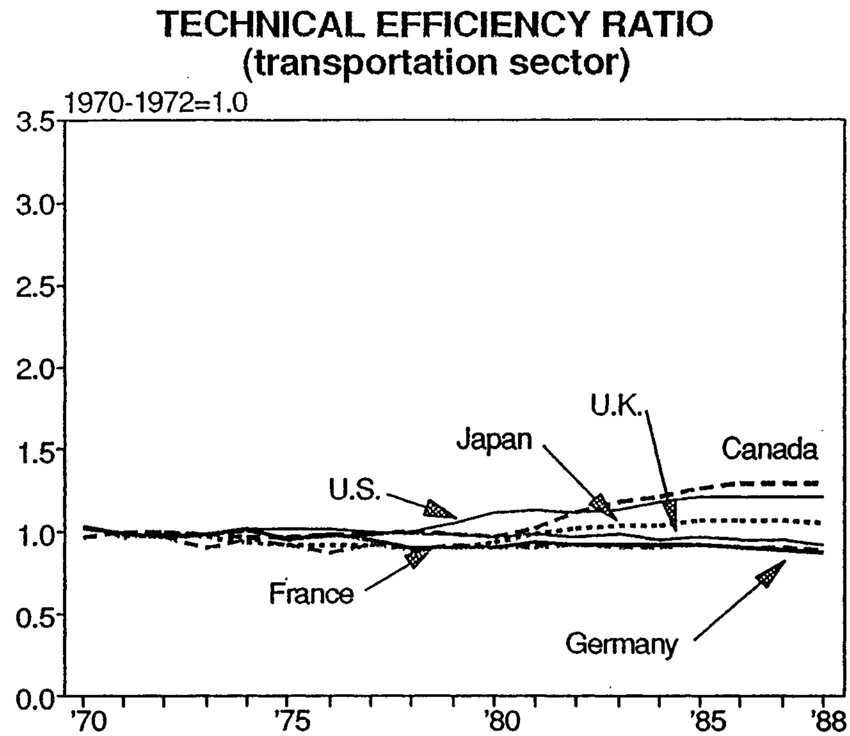
Year	U.S.	Japan	Germany	U.K.	France	Canada
1970	1.02	1.03	1.04	1.02	1.04	0.98
1972	0.99	1.00	0.98	0.98	0.97	1.00
1974	1.01	0.95	1.02	1.02	0.95	0.98
1976	0.97	0.92	0.99	1.03	0.88	0.99
1978	1.01	0.91	0.91	1.00	0.90	1.01
1980	1.12	0.94	0.92	0.97	0.91	0.98
1982	1.12	1.02	0.92	0.98	0.92	1.11
1984	1.18	1.04	0.92	0.96	0.91	1.22
1986	1.21	1.07	0.91	0.95	0.91	1.30
1988	1.22	1.06	0.88	0.93	0.89	1.30

The TERs for the transportation/non-transportation sectors shown in Figures 10 and 11 and Tables 20 and 21, respectively, suggest some interesting relationships. First, gains in oil efficiency in the transportation sector were well below those for nontransportation. This is not surprising because the opportunity for the substitution of alternative energy sources is greater for nontransportation than for transportation. Figure 10 also indicates that these ratios tended to remain closely bundled until the 1979-1980 oil price shock, after which the ratios for the U.S., Canada, and to a lesser degree Japan, broke from the pack.

A somewhat surprising result was that three of the six countries (France, Germany, and the U.K.) recorded TERs for transportation that declined and one country (Japan) recorded a transportation efficiency ratio that increased only modestly. During the 1970-1988 period, percentage changes in the transportation TERs ranged from a decline of 13 percent for Germany to an increase of 27 percent for Canada. The gain in the U.S. TER was 20 percent.

In those countries where gains were recorded the data suggest that it took the transportation sector some time to adjust to the initial shock of higher oil prices in 1973-1974 and the subsequent shock in 1979-1980. The major gains occurred post-1980.

Figure 10:



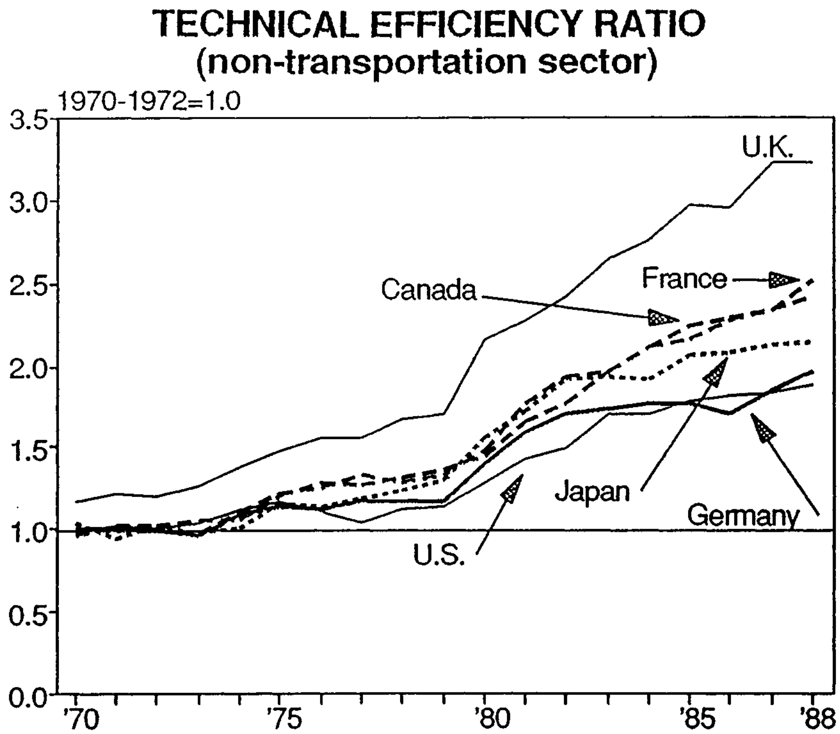
Source: Derived from OECD.

The pattern of change in the TERs for the nontransportation sector was markedly different from that of the transportation sector (see Figure 11). All six of the countries recorded substantial gains in oil efficiency in nontransportation--gains ranged from 64 percent in the U.S. to 117 percent in the U.K. One might expect that the heterogeneous nature of this sector, with its greater diversity of potential energy sources and substitutability, contributed to the progressive improvement in the efficiency ratio throughout the period.

The second approach to examining the geographical size/transportation issue looks directly at the geographical size component of the economies. The per capita consumption measures used in the energy dependence discussion earlier is modified to incorporate country size. The modification is accomplished by constructing a standard population density series for each country across the 1970-1988 period. This results in two series per country--oil consumption relative to density for the transportation sector and oil consumption relative to density for the nontransportation sector.

The data indicate that low population density does appear to go hand-in-hand with high oil consumption. Both the U.S. and Canada recorded much higher consumption to density figures than did the other countries (see Tables 22 and 23) These data also indicate that oil consumption in transportation, relative to population density, increased through out the period in France, Germany, Japan, and the U.K. On the other hand, the U.S. and Canada recorded declines in consumption relative to density in transportation from the late 1970s, although the data showed an up-tick in 1988.

Figure 11:



Source: Derived from OECD.

Table 21: Technical energy efficiency ratio for the nontransportation sector
(1970-1972 average = 1.0)

Year	U.S.	Japan	Germany	U.K.	France	Canada
1970	0.98	1.04	1.01	1.17	1.01	0.96
1972	1.00	1.02	0.99	1.20	0.99	1.02
1974	1.11	1.00	1.08	1.37	1.11	1.06
1976	1.11	1.13	1.11	1.56	1.24	1.28
1978	1.12	1.24	1.16	1.68	1.29	1.32
1980	1.28	1.56	1.39	2.16	1.48	1.45
1982	1.49	1.92	1.70	2.42	1.92	1.77
1984	1.70	1.92	1.76	2.76	2.10	2.11
1986	1.81	2.07	1.70	2.94	2.27	2.28
1988	1.89	2.14	1.96	3:22	2.51	2.42

In the nontransportation sector the geographical size of the U.S. and Canada also appear to dominate the data. The data for the U.S. does indicate a decline in oil consumption relative to population density, albeit from comparatively high levels. The U.K. and France also recorded reductions in oil consumption relative to population density.

In short, it would appear that geographic size does influence an economy's level of oil use efficiency in the transportation sector, and also in the nontransportation sector.

Table 22: Oil consumption by transportation sector relative to population density
(million tons oil equivalent/population density)

Year	U.S.	Japan	Germany	U.K.	France	Canada
1970	6.11	0.05	0.05	0.05	0.09	5.25
1972	6.65	0.05	0.05	0.05	0.10	5.68
1974	6.67	0.05	0.05	0.05	0.11	6.28
1976	7.06	0.06	0.05	0.05	0.12	6.47
1978	7.34	0.06	0.06	0.06	0.13	6.57
1980	6.34	0.07	0.07	0.06	0.13	6.90
1982	6.44	0.07	0.06	0.06	0.13	5.87
1984	6.62	0.07	0.07	0.06	0.14	5.77
1986	6.73	0.07	0.07	0.07	0.14	5.77
1988	7.07	0.08	0.08	0.07	0.15	6.21

Table 23: Oil consumption by nontransportation sector relative to population density
(million tons oil equivalent/population density)

Year	U.S.	Japan	Germany	U.K.	France	Canada
1970	15.25	0.23	0.23	0.20	0.43	14.54
1972	15.54	0.25	0.24	0.20	0.45	15.54
1974	15.02	0.27	0.24	0.20	0.45	16.63
1976	14.79	0.26	0.25	0.19	0.42	16.96
1978	15.03	0.25	0.25	0.19	0.45	17.39
1980	14.30	0.24	0.25	0.17	0.44	17.56
1982	12.71	0.22	0.22	0.17	0.39	16.18
1984	13.03	0.24	0.23	0.16	0.40	16.60
1986	12.40	0.23	0.24	0.17	0.39	16.69
1988	13.18	0.25	0.23	0.17	0.38	17.42

CONCLUSION

Dependence on energy is a fact of life for the world's economies. How dependent and on what energy forms that dependence relies is not universally alike. On the contrary, there appear to be substantial differences across countries in their level of aggregate dependence, the form of that dependence, and how they have responded to changes in the energy environment following the 1973-1974 oil shock.

While oil continues to dominate the energy picture in each of the six countries, each of the countries has reduced its relative dependence on oil, at least from those periods of highest dependence in the late 1970s. But it is also the case that the alternative energy sources toward which these economies have shifted tend to be hydrocarbon fuels, specifically coal and natural gas. The U.S. increased its relative dependence on coal. Germany, Japan, the U.K., and to a lesser degree France, increased their relative dependence on natural gas.

Indeed, as of 1988, hydrocarbon fuels continued to provide 85 percent to as much as 92 percent of total fuel requirements in Japan, Germany, the U.S. and the U.K. (in 1970, hydrocarbons provided well over 90 percent of fuel requirements in each of these countries).

Only in France and Canada do nonhydrocarbon fuels constitute a conspicuous portion of their economies' energy sources. In 1988, for example, nuclear and H-G-S energy provide 38 and 35 percent, respectively, of France's and Canada's energy requirements. France in particular has moved well away from dependence on hydrocarbon fuels toward nuclear power during the period examined. Not only did it maintain a comparatively low per capita total energy requirement but it also maintained a comparatively low reliance on oil and hydrocarbon fuels in general. In relative terms, Canada moved well away from hydrocarbon fuels as a general category, but because of its high per capita total energy requirements, the highest of the six countries, its dependence on oil remained high.

An economy's reliance on energy depends on numerous factors. Central to how an economy responds to shocks in prices or the availability of its energy resources is how efficient the economy is in energy utilization. Standard technical efficiency measures indicate that each of the six economies have recorded substantial overall gains in technical efficiency. In the U.K. the efficiency ratio for GDP-to-energy input stood 39 percent higher in 1988 than in 1970. In the U.S., which ranked third in overall efficiency gains behind Japan, technical efficiency was up 31 percent.

As one would expect, these gains are not uniform across sectors within an economy and the pattern of gains across sectors varies considerably between countries. Gains in technical energy efficiency in U.S. industry were only modestly greater (up 35 percent between 1974 and 1987) than for the nonindustrial sector (up 31 percent). In Japan and Germany, technical energy efficiency gains in industry were dramatically larger (up 80 percent and 42 percent, respectively) than in the nonindustrial sector (up 13 percent and 7 percent, respectively). This differential in technical efficiency gains could be expected to be a factor in maintaining or enhancing international competitiveness by reducing energy input costs, thus possibly helping to offset the adverse competitive implications, for Germany and Japan, of the dollar's depreciation in foreign exchange markets.

Several points stand out from this examination of energy dependence and efficiency: The major industrial economies continue to be heavily dependent on oil and other hydrocarbon fuels. Among those countries, Canada and France have made substantial strides in shifting their dependence to nonhydrocarbon fuels. In the aggregate, energy is more efficiently utilized than it was prior to the 1973-1974 oil shock. The gains in energy efficiency in the U.S. have been spread rather evenly across the industry and nonindustrial sectors of the economy. The efficiency gains in Japan and Germany were primarily in the industrial sectors of the two economies.

Much work remains to be done concerning the issues of energy dependence and efficiency. Because of the problems noted above concerning the measurement of efficiency levels in cross-country analysis, there is need for further work concerning the measurement of efficiency, as well as further study of the impact of geographical size on energy utilization and the impact of prices, environmental concerns, and government polices on energy use and efficiency.

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FOOTNOTES

[1]Currently, the Congress is considering an omnibus energy production and conservation bill, the major focus of which is to promote increased domestic oil production (and reduced dependence on foreign oil) by relaxing drilling restrictions in Alaska and in offshore areas. Also under consideration are measures to decrease oil consumption through administrative auto mileage requirements and another token increase in the gasoline tax of 5 cents per gallon.

[2]One might assert that this fragility is also due to an apparent lack of appreciation by policy makers of their economies' dependence on energy, especially petroleum, for continued economic viability. This is exemplified by a lack of will in some countries, especially the U.S., to apply significant economic disincentives (e.g., gasoline taxes) to the consumption of energy and oil. The preference instead is for administrative distortions to the market place.

[3]Measures of energy utilization used in this study draw on the Organization for Economic Cooperation and Development (OECD) definition of domestic "Total Primary Energy Requirement" (TPER) and "Total Final Consumption" (TFC). Where a common energy unit is required in the analysis the OECD's common energy unit, "tons of oil equivalent," usually measured in millions (Mtoe) is used.

During any given period, TPER is defined as the sum of a country's internal production of all energy resources, plus imports, less exports, less international marine bunkers, plus or minus inventory changes of these resources. This measure differs from TFC primarily in that TPER includes energy used in the transformation process, e.g., coal to electricity, and distribution losses as in the transmission of electricity. Energy forms also differ between TPER and TFC. Nuclear or solar energy contribute toward fulfilling a country's energy requirements, TPER, but are not used directly in consumption, TFC. Nuclear or solar energy is consumed in the form of electrical energy, and thus does not appear directly in energy consumption.

The OECD defines a "ton of oil equivalent," where ton refers to a metric ton (2,204.6 U.S. pounds), as equal to 10^7 kcal. of energy. All energy forms, be they petroleum, nuclear power used to generate electricity, or electricity consumption itself are converted to the common unit "t.o.e." In this article units will be reported in millions of ton oil equivalent (Mtoe).

[4]Percentage changes throughout the article are reported on a logarithmic basis.

[5]Import dependence has implications for a country's international balance-of-payments. The larger the oil import requirement needed to sustain the economy, the greater the real resources required to finance the importation of oil. Other things remaining the same, a lower standard of living results for the oil importing country than if the oil could be sourced at equal cost domestically.

Import dependence is also a concern for national security. The greater a country's dependence on imported oil the less independent it is from the political or economic whims of its foreign oil suppliers. It is clear that in the current political/economic environment, energy and petroleum security is vital. From a near-term perspective, it may be undesirable to be dependent on the political or economic whims of foreign oil producers, however, one must also be aware of longer-term security issues.

Arguably, a nation's energy sources would be more secure the less its dependence on foreign supplies. During 1989-1990, 40-45 percent of U.S. petroleum consumption was derived from foreign sources. On the other hand, in an environment of limited and relatively high cost domestic supplies and relatively inexpensive foreign supplies the utilization of imports serves to conserve and prolong those limited domestic supplies, should a real emergency develop. U.S. petroleum independence in the near-term--the relatively more rapid depletion of domestic supplies--risks the possibility of becoming more heavily dependent on foreign supplies in the future, barring major technological innovation, such as, for example, economically viable solar or fusion power. From an energy security perspective then, it is not a clear cut decision that reduced import dependence now is preferable to necessarily greater dependence later. This is an argument that policy makers must not continue to ignore.

[6]It is interesting to note how the region of source has changed over time. From 1973 to 1988 the proportion of total oil consumption by the six countries that was derived from the Persian Gulf states generally declined: For Japan, from 74 percent to 55 percent; for France, from 84 percent to 28 percent; for the U.K. from 66 percent to 15 percent; for Germany, from 49 percent to 9 percent; and for Canada, from 19 percent to 4 percent. The U.S. share increased from a comparatively low level of 6 percent to 9 percent.

[7]American Gas Association (1990), p. 124.

[8]In the physical sciences the output measure in the output/input relationship, refers to actual output relative to potential output. For example, the question of how efficient a system is examines what output is actually derived as compared with the potential output given some specified input. The greater the output relative to potential output the more efficient the system. Unfortunately, the exact of this definition implies an information and measurement luxury unavailable to economics. Nonetheless, I use the expression "efficiency" in this paper, advisedly to be sure, but for lack of a better term.

[9]Gross domestic product is used as the measure of a country's output in order to obtain a more consistent data series. GDP is the more commonly used output measure abroad. GDP differs from GNP in that GDP excludes net factor income from abroad. In U.S. national income statistics, for example, most of the net factor income from abroad is in the form of U.S. firms' corporate profits from abroad--profits earned abroad are not part of U.S. GDP, but are included in GNP.

[10]Other economists, for example,-Summers and Heston (1984), have done extensive work that has focused on developing meaningful measures of real national product across countries.

[11]Organization for Economic Cooperation and Development (1991).

[12]OECD data are available for energy and oil consumption by transportation (air, road, and rail). An important restriction in the transportation case is the lack of contribution to GDP by sector data, as was the case for industrial/nonindustrial sectors--that is, contribution to GDP by the transportation sector and contribution to GDP by the non-transportation sector. The technical efficiency measures, therefore, do not refer specifically to this sector. Rather, they are a hybrid that relates total GDP output to energy inputs for transportation/nontransportation.

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