Manufacturing Energy Use in OECD Countries: Are Energy Intensities Still Falling?

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ABSTRACT

This paper examines manufacturing energy use in thirteen OECD countries over the period 1971 to 1995. Changes in energy use are described through using the Adaptive Weighting Divisia index to enable decomposition of energy use into changes in the overall output of manufacturing, the structure of output, and the energy intensity of each sub-sector, and to consistently compare the results across countries.

The development in the periods after the oil price shocks of 1973 and 1979 are compared with the period of relatively stable energy prices after the oil price crash of 1986. The results show that manufacturing output grew in most countries, pushing up energy use. Changes in the structure of output drove up energy use between 1973 and 1995 in some countries and down in others. Changes in sectoral energy intensities had a profound and downward effect on manufacturing energy use in all countries. However, contrasting the period after oil prices fell in 1986 with earlier years shows that for most countries the rate of energy intensity decline slowed slightly but did not reverse with falling prices. In a few countries efficiency improvements continued to have a strong effect. This suggests that even without higher prices, improvements of energy efficiency seems to take place. The paper discusses how other factors than prices can have affected energy use in this sector.

Introduction

This paper builds on a series of studies of energy use in manufacturing in OECD countries. Refer to (Unander et al., 1999); (Torvanger, 1991), (Howarth *et al.*, 1991) and (Unander and Schipper, 1997). In this paper the analysis is expanded to thirteen OECD countries (Australia, Canada, Denmark, France, Finland, West Germany[1], Italy, Japan, the Netherlands, Norway, Sweden, United Kingdom, United States) and the period of observation is extended to 1994 or 1995. Companion papers compared different methods of indexing energy use (Greening, Davis, Schipper, and Khrushch, 1997) and then applied an advanced index, the Adaptive Weighting Divisia (AWD) index, to the factorial analysis of carbon emissions from manufacturing (Greening, Davis, Schipper, 1996). Based on that work, a rolling base year specification for the AWD index is used in this paper to describe changes in aggregate energy intensity.

We start out by giving a brief overview of the methodology and data used in this study. We then present overall trends in manufacturing energy use, output, and aggregate energy intensity before we investigate in more detail the impact changes in the structure of manufacturing output and energy intensities of each sub-sector had on total manufacturing

[1] We use West Germany to refer to the territory of the former Western Germany, as our analysis excludes manufacturing in East Germany.

energy use. We compare trends over time and across countries, and based on these results we discuss prime factors that may have caused the observed changes in energy intensity to come about.

Methodology and Data

We disaggregate manufacturing energy use into six separate sub-sectors and a sub-sector that contains all remaining sub-sectors of manufacturing (here called "other manufacturing"), using the United Nations International Standard Industrial Classification (UN, 1990). These are: food and kindred products (ISIC 31); paper and pulp (ISIC 341); chemicals (ISIC 351 and 352); non-metallic minerals (ISIC 36); iron and steel (ISIC 371); and non-ferrous metals (ISIC 372). With the exception of food and kindred products, these sub-sectors are all energy-intensive, and we will sometimes refer to them as production of raw materials. Petroleum refining (ISIC 353/4) is excluded from this analysis for all countries.

For each of the sub-sectors, we examine the structure of output (measured as shares of real value added[2] in each sub-sector, including the other manufacturing sub-sector) and the energy intensity, measured as delivered energy[3] per unit of real value added. To evaluate changes in each country's manufacturing energy use, and to compare changes over time by country, we decompose changes in total energy use into impacts from changes in manufacturing output, structure, and sub-sectoral energy-intensity, using a rolling Adaptive Weighting Divisia index method. Refer to (Greening *et al.* 1996) for more details. We use economic measures to represent output because of the near impossibility of measuring accurately the energy intensities of individual manufacturing products over a long period of time for all countries, and the even more difficult problem of representing manufactured products by a few well-defined raw materials for which physical energy intensities are known.

Data are taken from national energy balances and industrial statistics, as described in (Howarth, Schipper, Duerr and Stroem, 1991), (Howarth, Schipper, and Andersson, 1993), (IEA, 1997), and a series of national energy-use studies for Norway (Unander, Alm and Schipper, 1997), Denmark (Schipper *et al.*, 1995), Sweden (Schipper *et al.*, 1993), and Finland (Schipper *et al.*, 1995). Analyses of US manufacturing were described in Howarth (1990) and Golove and Schipper (1995). For most countries we analyzed manufacturing energy consumption data from 1970 to 1995,[4] while for West Germany, Japan, and the US we also have data covering the period between 1960 and 1970.

Output is measured as value added components of GDP originating in each sub-sector of manufacturing. Real value added components of GDP series for years 1970-95 were obtained from the OECD STAN Database for each country, except for Australia and Sweden,

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[2] Value added is defined as gross output from manufacturing production less the value of intermediate consumption. This study uses value added measured in real 1990 US$.

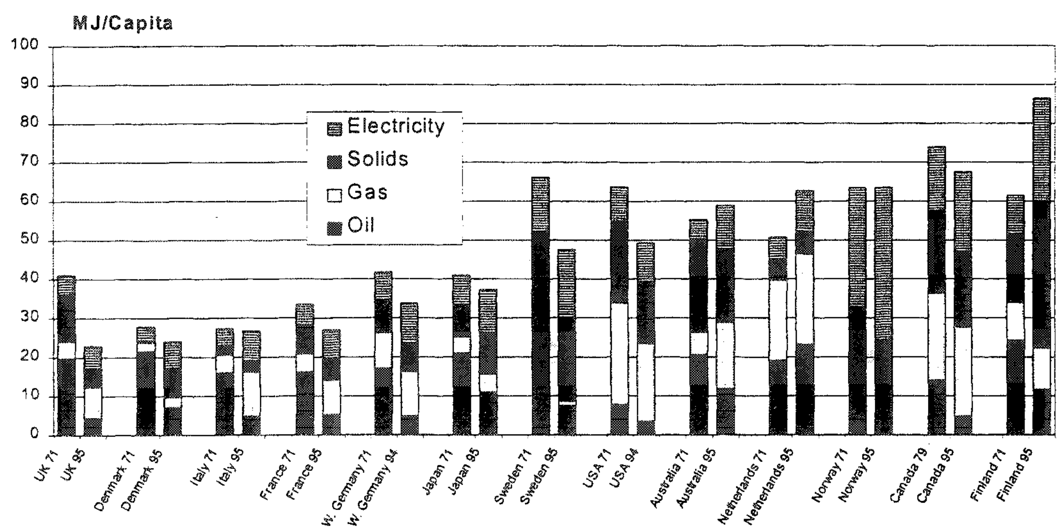
[3] Delivered or final energy is defined as the amount of energy that the consumers purchase, and does not account for losses in the energy sector (as the term primary energy does). Subtracting end-use losses from final energy yields the term useful energy.

[4] For Canada energy consumption data were available only from 1979, while for Netherlands data from 1970 to 1979 were taken from IEA Energy Balances. For US and West Germany data were available only up to 1994, and for France and the UK starting in 1971.

where the data are taken from national statistical sources. After deflating each output series to real, 1990 currency, each country's output was converted to US dollars at 1990 purchasing power parity exchange rates.

Trends in Manufacturing Energy Use

During the period from 1970 to 1994 manufacturing energy use in the majority of the thirteen OECD countries ("OECD-13") under analysis declined steadily. Since energy use in most other sectors of the economy grew during the same period, manufacturing energy use today accounts for a significantly lower share of total energy than in 1970. Figure 1 shows that manufacturing energy consumption on a per capita basis fell everywhere except in Australia, Finland, the Netherlands, and Norway, despite the rapid growth in electricity use that took place in all countries.



Note: Biomass is included in solids and district heat in electricity. Data for Canada prior to 1979 are not available.

Figure 1. Manufacturing Delivered Energy Use per Capita: 1971 and 1994-95

The fuel mix began its evolution from solids and oil and/or oil and gas to electricity well before 1973 in most countries. The share of electricity also increased because of the marked drop in fuel intensity in all sub-sectors, not necessarily from direct substitution of electricity for oil, although this did occur in Finland and France in some industries and in Sweden and Norway when there was excess hydro or nuclear electricity. The rapid increase in the price of oil, followed by gas (and to some extent coal) accelerated this change.

However, only some of the observed changes in final fuel mix over this period of time may be attributed to relative levels in price of the different fuels; in addition, such factors as a change in industrial structure and changes in manufacturing processes contributed to changes in final fuel mix. Some of the change in fuel mix arose because of the decline in the importance of iron/steel and non-metallic minerals, the two sectors with a traditional affinity for coal, while the increase in biomass was largely a consequence of the increasing importance of the paper/pulp industry as well as a significant shift to biomass (wood and paper-making residues) in that sector.

Trends in Manufacturing Output

Within the thirteen OECD countries analyzed in this paper, manufacturing value added more than doubled between 1970 and 1995, at an average rate of 2.5% per year. However, this growth was not constant over time; three periods of economic recession, 1973-75, 1979-82, and 1990-93, interrupted the growth. This is illustrated in Figure 2 where the development of total manufacturing output for the thirteen countries is represented by the line plotted on the left axis. As the figure shows manufacturing output in OECD-13 did not recover back to 1990 level until 1994. For most countries the recessions following the two oil crises in 1973 and 1979 affected the manufacturing sector relatively harder than other sectors of the economies, see Figure 2, where manufacturing share of total GDP is plotted on the right axis.

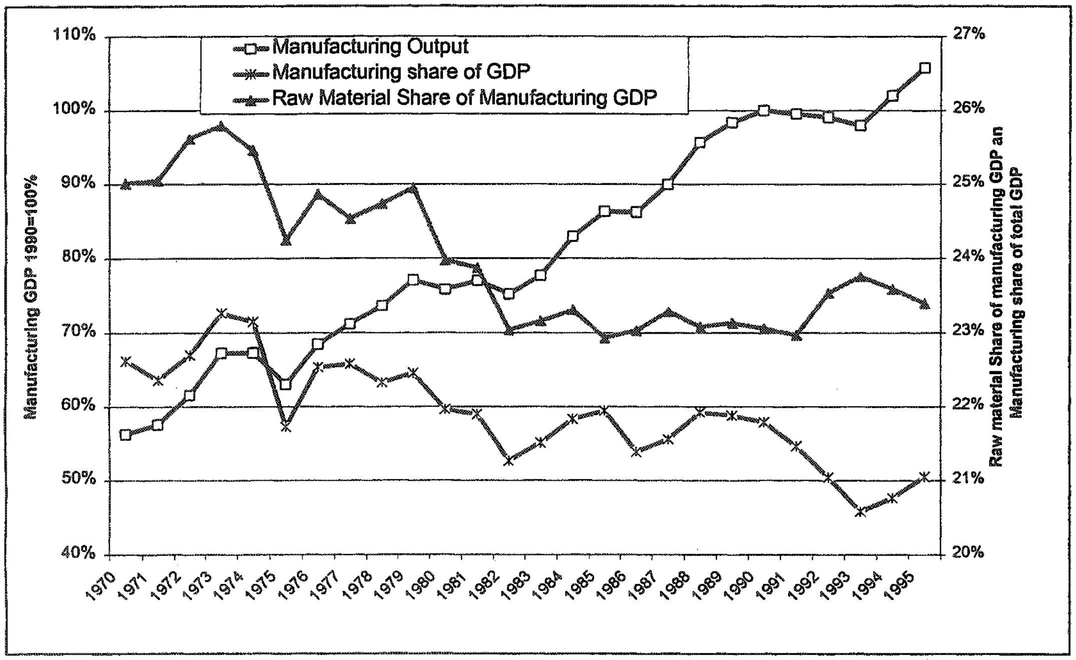


Figure 2. Manufacturing Output, Manufacturing Share of GDP, and Raw Material Share of Manufacturing Value Added: Aggregated Trends for 13 OECD Countries

In the recovery periods of 1975-79 and 1982-90 growth in manufacturing usually exceeded growth in the overall economy, with manufacturing GDP share for OECD-13 returning almost to the same level in 1989 as in the early 1970s. All countries experienced reductions in their manufacturing GDP shares in the years following 1990, which confirms the trend seen during the previous recessions. Interestingly, the share of energy intensive raw materials in manufacturing output had a similar development as manufacturing GDP share (see again Figure 2). This share also fell after both oil price shocks and recovered, or at least stabilized, in the immediate years after the recessions. However, after the recession following 1990, production of raw materials actually increased relative to other manufacturing.

Figure 3 (left axis) shows manufacturing output in 1973 and 1995 relative to 1990 level for all thirteen countries. Japan, Italy, Finland, and the US achieved the highest growth over the 1973 to 1995 period, while the slowest growth occurred in the UK, Norway, and West Germany. In Norway and the UK this is partly due to the rapid expansion of the oil sector that took place in the same period. The general trend in OECD-13 illustrated above with reduced output after the two oil price shocks can also be seen for most of the individual countries, although, especially the first price shock, appeared to have a greater impact on the larger economies. Comparing the bar for 1995 with 1990-level illustrates how countries have reached different stages in their recovery after the recession in the early 1990's. In most countries production has picked up, with France, Japan and to some extent, the UK still lagging. The results for West Germany are greatly affected by the reunification with former DDR.

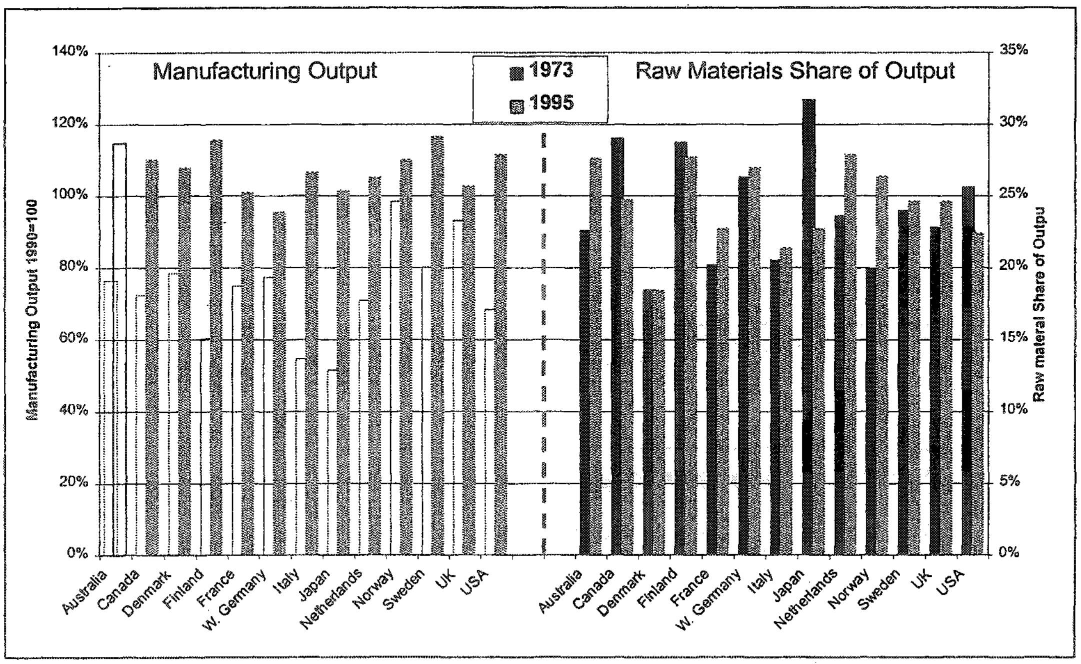
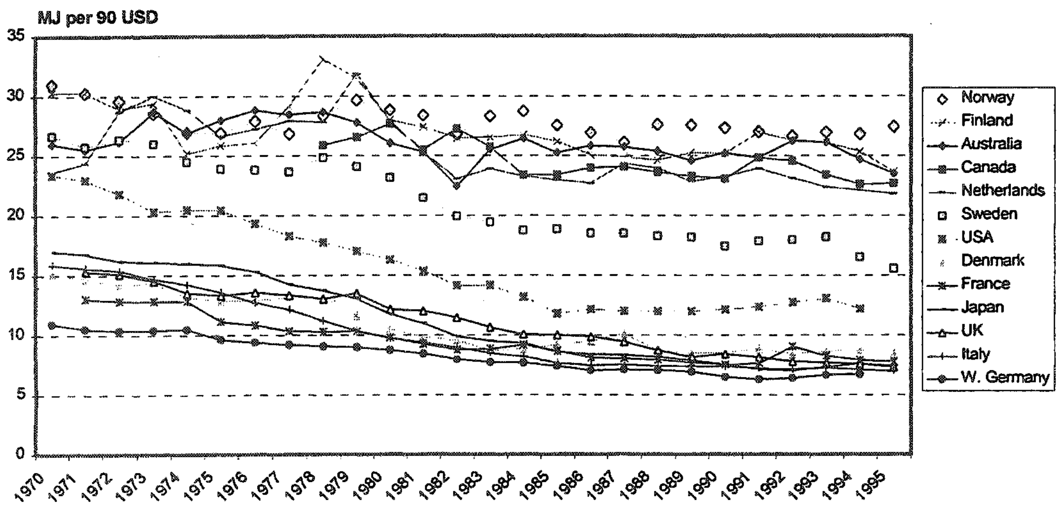


Figure 3. Manufacturing Output and Raw Materials Share of Total Output: 1973 and 1995

The right part of Figure 3 shows the share of energy intensive raw materials for 1973 and 1995. In most countries, the share in 1995 was between 20 and 30%, with Denmark lower than the other countries, and the Netherlands, Australia, Finland, and West Germany higher. With the exception of Australia with its abundance of cheap electricity, the share of raw materials production fell in every country after the economic disruptions following the first oil shock. After the second oil price hike this pattern was repeated, with the exceptions of France, Italy, and Norway, where raw materials kept or increased their share of the manufacturing production. Throughout the 1980s, the raw materials share grew or stayed constant in most countries, with the result that the share in 1995 exceeded the share in 1973 in all countries but Canada, Finland, Japan, and the US.

Aggregated Energy Intensity

Dividing total manufacturing energy use by manufacturing value added, yields a measure of aggregate (delivered) energy intensity. The development of this intensity for each country is shown in Figure 4. The decline is evident for most countries, as is the large spread in values among countries clearly indicating differences in manufacturing structure. Three groups of countries can be defined based on manufacturing energy intensity: the high-intensity countries (Australia, Canada, Norway, Finland, and the Netherlands), the medium-intensity countries (Sweden and the US), and the low energy intensity countries (all remaining countries). Sweden, the country that experienced the largest substitution of electricity for oil, moved from the group of high energy intensity countries to medium energy intensity in the last 20 years.



Note: Countries in the legend are listed in descending order according to their 1994 values.

Figure 4. Aggregate Energy Intensity (Manufacturing Delivered Energy Use per Value Added)

What is the meaning of the large spread in aggregate intensity among countries? Obviously the composition of the manufacturing production plays a significant role for the energy use in this sector. As an attempt to normalize for the differences in the mix of output, we calculated the energy intensity that would have occurred in each country if they all had the same shares of sub-sectoral output that make up the average for all 13 countries. In other words, the normalization attempts to equalize the structure of output everywhere by multiplying each country's sub-sectoral intensity by the respective sub-sectoral shares given by the average OECD-13 structure. This intensity is shown in Figure 5 *(OECD-13-structure)* next to the actual aggregate manufacturing intensity in 1994. Where the intensity increases in the alternative normalization (US, UK, Italy, France), the country in question had an output structure less energy intensive than the average of all countries; where a decline occurred the structure was more energy intensive. For Australia, the Netherlands, Finland, Norway and

Canada, the difference is large, indicating the importance of the high shares of energy intensive products. The third column in Figure 5 (*OECD-13 intensities*) displays the energy intensity that would have occurred in each country if they all had the average energy intensity for the 13 countries in every manufacturing sector, but their own sectoral output mix. In this case, increasing energy intensity (France, West Germany, Japan, Italy, and the UK) compared to the actual value means that a country's energy intensities are lower than the average for all countries; and a decline indicates that the intensities are higher than average. This is especially the case for the big producers of raw materials; Australia, Canada, the Netherlands, Norway, and Finland. Note that the US is the only nation with higher energy intensity than average, and at the same time having a (slightly) less energy intensive structure than average within our group of countries.

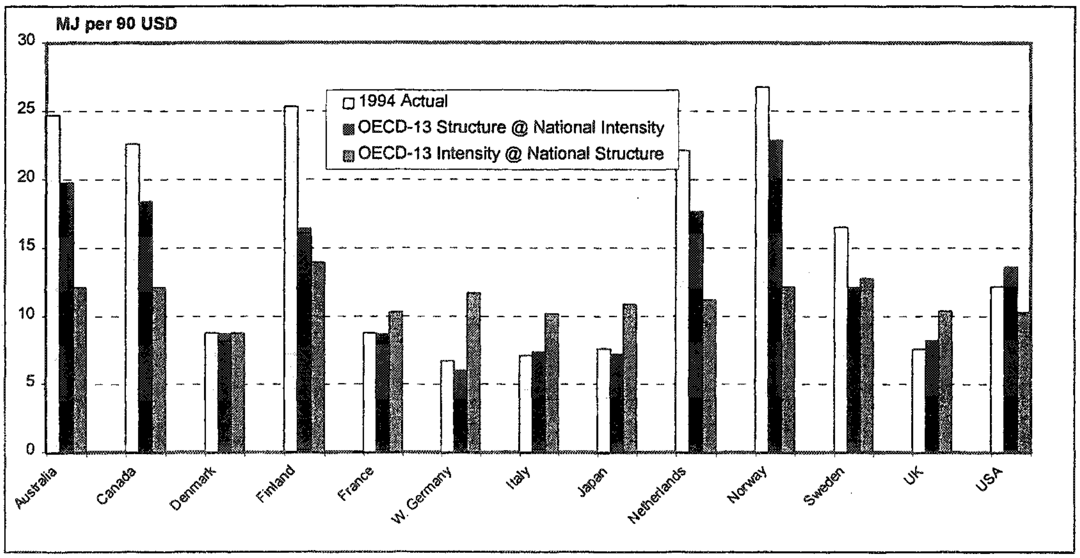


Figure 5. Delivered Energy Intensity in Manufacturing: 1994 Actual, OECD-13 Average Structure and OECD-13 Average Intensities

If we examine intensities in each sub-sector we see in general a similar spread across countries as on aggregate level. Intensities in West Germany, Japan, or Italy (in comparable sub-sectors) tend to be lower than those in the US or the UK, while intensities in Australia, Canada, Finland, Sweden, and Norway tend to be higher than the average. The higher intensities in these countries reflect the contribution of the paper and pulp, and metals sub-sectors, which are more energy-intensive than in the other countries because of the high production of raw pulp and raw steel and/or raw aluminum. These effects cannot easily be isolated at a 3-digit ISIC level of comparison. This energy-intensive structure accounts for a significant amount of the differences in aggregate intensity. Indeed, if we could fully disaggregate energy use and output at the 4-digit level for chemicals, non-ferrous metals, and even paper and pulp, we suspect some of the differences in Figure 5 in the third column would go away. However, this level of disaggregation is beyond the scope of this paper.

Impact of Changes in Structure and Energy Intensity

To investigate the impact of structural changes separately from changes in energy intensities in each sub-sector we use the AWD decomposition method to calculate the cumulative indices of changes in energy use due to each of these two components and a third, changes in the level of manufacturing output. Table 1 shows the results of decomposing energy use into these three factors expressed as average percentage change per year for three different time periods.

Table 1. Average Annual Rates of Change in Manufacturing Energy Use, Output, Structure, and Intensity

	Energy Use			Output			Structure			Energy Intensity		
COUNTRY	1973-1986	1986-1990	1990-1994	1973-1986	1986-1990	1990-1994	1973-1986	1986-1990	1990-1994	1973-1986	1986-1990	1990-1994
Australia	0.3%	2.6%	1.3%	1.1%	3.2%	1.9%	0.6%	1.6%	-0.6%	-1.4%	-2.2%	0.1%
Canada		0.7%	0.8%	2.0%	1.7%	1.4%		-0.5%	0.3%		-0.5%	-0.8%
Denmark	-1.1%	-3.3%	1.5%	2.1%	-0.6%	0.9%	-0.3%	-0.1%	0.0%	-2.9%	-2.6%	0.7%
Finland	1.7%	3.3%	1.8%	2.9%	3.2%	1.6%	-0.1%	0.3%	1.6%	-2.0%	-0.2%	-1.5%
France	-2.3%	1.3%	0.7%	1.2%	3.2%	-0.5%	-0.2%	0.1%	0.0%	-3.3%	-2.0%	1.2%
W. Germany	-1.8%	0.6%	-0.5%	1.1%	2.7%	-1.4%	-0.1%	-0.5%	1.0%	-2.7%	-1.6%	-0.1%
Italy	-1.8%	3.8%	-0.7%	3.4%	4.0%	0.2%	0.0%	0.2%	0.4%	-5.2%	-0.4%	-1.4%
Japan	-1.8%	3.5%	-0.1%	3.2%	6.3%	-0.4%	-2.0%	-0.2%	0.1%	-3.0%	-2.6%	0.2%
Netherlands	-0.4%	3.5%	-0.7%	1.8%	2.8%	0.6%	1.5%	-0.1%	1.0%	-3.6%	0.8%	-2.3%
Norway	0.1%	-0.9%	1.5%	0.5%	-1.3%	2.0%	0.6%	2.2%	0.8%	-1.1%	-1.8%	-1.3%
Sweden	-1.4%	0.0%	0.0%	1.3%	1.5%	1.3%	-0.4%	0.3%	2.8%	-2.2%	-1.9%	-4.1%
UK	-3.6%	0.0%	-2.4%	-0.6%	3.9%	0.2%	-0.4%	-0.3%	-0.5%	-2.6%	-3.6%	-1.6%

The structure results represent the evolution of energy intensity that would have occurred if total sectoral output and energy intensities of each industry group had remained constant at their 1990 levels, allowing us to focus on only those changes that resulted from structural shifts in the sub-sectoral output mix. Over the entire time period from 1970 to 1994 structural changes reduced energy use by 18% in Japan and by 15% in the US, while the effect of changing manufacturing structure increased energy use in the Netherlands, Norway and Australia, by 43%, 27% and 13%, respectively. In the remaining nations, the manufacturing structure in 1990 was about as energy-intensive as in 1970. This shows that movement towards a less energy intensive product mix over this 25-year time period has not been significant outside the US and Japan.

The decline in energy use in US from structural change was primarily caused by reductions in iron and steel production and the increasing share of other non-energy intensive manufacturing. The value added in iron and steel industry between 1970 and 1995 fell by 17%, while the value added of other manufacturing increased almost 125%, increasing its share in total manufacturing from 57% in 1970 to 68% in 1995. In Japan, most of the structural changes took place in the early 1980s, when all raw materials sectors experienced reduced shares of total manufacturing. In Norway inexpensive hydro-power resulted in the expansion of electricity-intensive production such as chemicals (fertilizers) and primary aluminum. The share of those industries in Norwegian manufacturing almost doubled, pushing the share of raw materials manufacturing to increase from 19% to 27% from 1970 to 1995. In Australia, inexpensive coal-based electricity had the same effect on the development of non-ferrous and chemical industry and the structural shift in manufacturing. The increase in the production of chemicals (fertilizers) caused the structural shift in manufacturing in Netherlands. The rest of the countries (West Germany, Finland, France, Italy, and Sweden) saw fluctuations in the shares of manufacturing output from energy-intensive production throughout the 1980s, all returning to about the same level in 1994 as in 1973. Ignoring fluctuations resulting from transient declines in general economic activity, we can only conclude that by 1994 energy use in Norway, Australia, and the Netherlands was significantly *higher* than in the early 1970s because of structural change, while that of Japan and the US and to some extent, Canada and the UK, was *lower*.

All the countries included in our study achieved reductions of energy intensities throughout the time period we have studied. Reductions between 1973 and 1995 are considerable, ranging from a 20% reduction in Australia to 47% in the UK.[5] The most rapid declines in intensities occurred in the 1979-1982 period, and with a couple of exceptions, the intensities kept declining almost everywhere until the mid-1980's. Although some countries experienced continued improvement of intensities after the fall in oil prices in 1986, the general trend has been slower rates of decline than in the periods with increasing prices, and in the early 1990s reductions slowed down even further in most countries. In Australia, Denmark, France, Japan, and the US energy intensity increased during 1990-94.

What has caused these changes in energy intensities over time? Increases in real prices for heavy fuel oil of between approximately 200 and 300 percent during the period between 1973 and 1985 obviously had its effect. They also resulted in a number of changes in the make-up of primary and delivered fuel mixes, including changes in the availability of natural gas in Europe. Price differentials between liquid, gaseous, and solid fuels contributed substantially to the decline in consumption of heavy fuel oil in manufacturing processes. The substantially higher, overall average cost of thermal energy in manufacturing during the period 1973 through 1985 also accelerated the rate of decline in energy intensity. However, these increases in the average productivity of energy required investment of capital and time.

It is hard not to attribute some of the decline in energy intensities to higher energy prices. Most of this happens as energy-saving technology substitutes for energy itself. Of course, other factors also affect the rate at which energy intensities decline. Capital costs affect the relative attractiveness of energy-saving investments, and capital costs were high, particularly in the early 1980s. The overall rate of growth in output in each sector influences the rate of reinvestment in new technology and the increases in the scale of production also affects energy intensities. Howarth (1991) argue that investments in new capital facilities are a principal source of energy intensity reductions. Indeed, there is a reason to believe that the lower manufacturing output in the US in the post 1973 period compared to the years prior to 1973 resulted in a significant slow-down in construction of new capacity, and thus reduced market penetration of state-of-the-art technologies. However, the decline in manufacturing intensities for the US was most rapid in the period of 1979-1982, one of very high energy prices but also very profound recession, which reached bottom in 1982. It appears that both

[5] Energy intensity changes have reduced energy consumption by 57% in Italy. However, results are heavily influenced by the lack of data separating ferrous and non-ferrous metals and the paper and pulp production from the less energy intensive printing processes.

prices and the rate of economic growth are important determinants of the rate of decline in manufacturing energy intensities.

Other factors that lowered manufacturing energy intensities are structural shifts in production inputs and manufacturing processes. Those included use of recycled feedstocks (scrap metal, recycled paper, etc.) in manufacturing processes and shifts from primary to secondary production (shift away from raw steel and aluminum production to secondary, shift from raw paper production to recycled paper production, etc.).

Thus the long-term trends indicate that the relative price of energy is not the only determinant of energy intensity. To be sure, the countries with higher prices for fuel and electricity (West Germany, Japan) have the lowest energy intensities, while those with lower prices (the Nordic countries for electricity, Australia for coal, the US and the UK for gas and oil) have the highest intensities. The decline in energy intensities may have been accelerated after the two oil shocks (with appropriate lags), particularly in countries where output increased the most. Similarly, this trend slowed after oil prices dropped in 1986, but in most cases it did not end except where recession occurred. Electricity prices did not "crash" dramatically in 1986, in part because most utilities had moved away from oil, and also because only a portion of the price of electricity was actually for primary inputs to generation itself. What is interesting about this period is that energy intensities on the whole continued to decline, both sector by sector and aggregated (holding structure constant). However, the rate of decline in delivered energy intensities after 1985 was slower than in the 1979-1985 period in all but one country. The decline in oil share slowed down everywhere except in Finland, Denmark, and Sweden, where the expansion of gas networks continued. However, it is clear that the fall of oil prices in 1986 did not bring the decline in energy intensities in manufacturing to a halt.

The trends in energy intensities have important consequences for emissions from manufacturing. As discussed in Schipper et al. (1997) and in Unander and Schipper (1999), CO_2 emissions in manufacturing (including those arising in production of power and heat purchased by manufacturing) fell even more than energy intensities did for most countries. Like energy intensities, however, CO_2 intensities fell less after 1990 than before. Although voluntary agreements for emissions reduction from manufacturers in a few countries attempt to address this slowdown, the long-term path of emissions from manufacturing is now of central concern to nations that have signed the Kyoto Protocol because so much of manufacturing output is traded internationally. Measures to stimulate further reductions in carbon intensity or indeed total carbon emissions have some cost, depending on the present position (and trends) of each industry branch in each country.

Conclusions

We have reviewed trends in the output, structure, and energy intensities of manufacturing in thirteen OECD countries over a period of nearly 25 years. Changes in energy use in manufacturing occurred through changes in several underlying components. Output grew in most countries, pushing up delivered energy use. Changes in the structure of output had significant effects on energy use between 1973 and 1994 in six countries, raising energy use in Australia, the Netherlands and Norway and reducing energy use by more than 15% in the US and Japan. Changes in energy intensities had a profound and downward effect on manufacturing energy use in all countries, with reductions in delivered energy intensity (holding the mix of output constant) ranging from 20% to 57% between 1973 and 1994. While formal analysis of the causal factors is not complete, we can say that higher energy prices, growth in output, and technological changes all contributed to lower energy intensities.

Contrasting post-1985 with earlier years we see that for most countries the rate of energy intensity decline slowed slightly but did not reverse with falling prices. What did occur, however, is an increase in energy intensity or reduction in the rate of decline in countries with recessions in manufacturing after 1989. Thus energy efficiency improvements did not fade away with the crash in world oil prices, although the pace has clearly slowed. Significantly higher prices after 1979 resulted in lower energy intensities in spite of recession, while generally flat prices in the 1989-94 period were only associated with a slowing of the decline in intensities, except where significant recession occurred.

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