Decomposition of Manufacturing Energy Use in IEA Countries: How Do Recent Developments Compare to Historical Long-Term Trends?

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ABSTRACT

This paper examines manufacturing energy use in ten IEA countries between 1973 and 1998. Changes in energy use are described through using Laspeyres indexes to enable decomposition of energy use into changes in the overall output of manufacturing (value added), the structure of output (industrial mix), and the energy intensity of each sub-sector, and to consistently compare the results across countries.

The results show that structural changes have reduced manufacturing energy use in most countries, particularly the U.S. and Japan. In a few countries, however, the manufacturing structure became more energy intensive and thus drove up energy use over the study period. For the group of ten IEA nations, the net effect of structural changes accounted for more than a third of the reduction in total manufacturing energy use per unit of output between 1973 and 1998. The rest of the reductions in this period can be explained by falling energy intensities in individual manufacturing branches. Contrasting post-1986 with earlier years shows that the rate of energy intensity decline in manufacturing has slowed in most countries.

Between 1994 and 1998 most countries experienced a strong growth in manufacturing output and a reduction in aggregated manufacturing energy use per unit output. However, the results of the decomposition analysis presented in this paper point to that this reduction was mostly due to a structural shift towards less energy intensive branches, such as electronics and electronic equipment, and that the impact from reduced energy intensities was close to nil for the group of ten IEA countries studied here.

Introduction

This paper compares the impact structural changes has had on manufacturing energy use to the impact induced by changes in branch-by-branch energy intensities (energy per value added) covering the period between 1973 and 1998. The paper builds on previous studies of manufacturing energy use published in *inter alia;* Torvanger (1991), Howarth and Schipper (1992), Greening et al. (1996), Unander and Schipper (1997) and Unander et al. (1999).

Changes in energy use are described through using Laspeyres indexes to enable decomposition of energy use into changes in the overall output of manufacturing (value added), the structure of output (relative shares of value-added among the sub-sectors), and the energy intensity of each sub-sector.[1] For comparison of different decomposition methods refer to Greening et al. (1997) and Ang and Zhang (2000).

[1] Energy intensity is measured in terms of economic output because of the near impossibility of accurately measuring the energy intensities of individual manufacturing products over long periods for all countries. Also, because of the daunting problem of representing manufacturing products by a few well-defined raw materials

The data used for this study are taken from IEA's energy indicator database. This database is being built up under the IEA project on energy indicators, IEA (1997), Schipper et al. (2001) and Unander (2001). The database allows for disaggregating manufacturing energy use into the following seven sub-sectors; paper and pulp; chemicals; non-metallic minerals; iron and steel; non-ferrous metals; food and kindred products; and one category including all remaining branches of manufacturing, here denoted "other industries". The first five sub-sectors are all energy-intensive, and this paper sometimes refers to them as production of raw materials.

The manufacturing energy data in the database are generally from IEA Energy Statistics and Balances for OECD countries, supplemented with data from national sources. In this paper energy use is measured as final, or delivered, energy. Value added data are measured in real terms (1995) and converted to U.S. dollars using purchasing power parities. Value added data are taken from the OECD STAN database.

Due to data limitations, the analysis focuses primarily on ten IEA countries covering the period from 1973 to 1998.[2].

Trends in Aggregate Manufacturing Energy Use

In 1973 the manufacturing sector accounted for 37% of the total final energy consumption in the IEA-10. By the late-1990s that share had fallen to about 27%. In fact, while total final energy consumption in these countries grew by 16% between 1973 and 1998, energy use in manufacturing fell by 14%.

The share of energy used for manufacturing has declined for three reasons. First, the share of manufacturing production (value added) in GDP has fallen slightly. Second, the ratio of energy use to output in most individual branches of manufacturing has fallen markedly, by as much as 50% since 1973. Finally, the mix of what is produced within manufacturing, i.e. the structure, has changed.

Consider Figure 1 where total final energy consumption (TFC) per unit of total GDP and manufacturing energy use per unit of manufacturing value added are shown for the IEA-10 [3]. Both indicators fell rapidly during the first years after the 1973 oil shock, while the decline has been more moderate since the mid-1980s, especially for manufacturing. The fall in TFC/GDP averaged 2.1% annually between 1973 and 1998, while the aggregate manufacturing energy intensity fell more, by 3.1% on average per year.

The manufacturing sector contributed to the fall in TFC/GDP through both the moderate reduction of the manufacturing share of total GDP (see next section), and through the fall in manufacturing energy use per value added. The key question this paper attempts to answer is how much of the fall in the latter is a result of structural changes within the manufacturing sector and how much is due to changes in individual energy intensities in each manufacturing branch? To estimate this, more disaggregated information than what is

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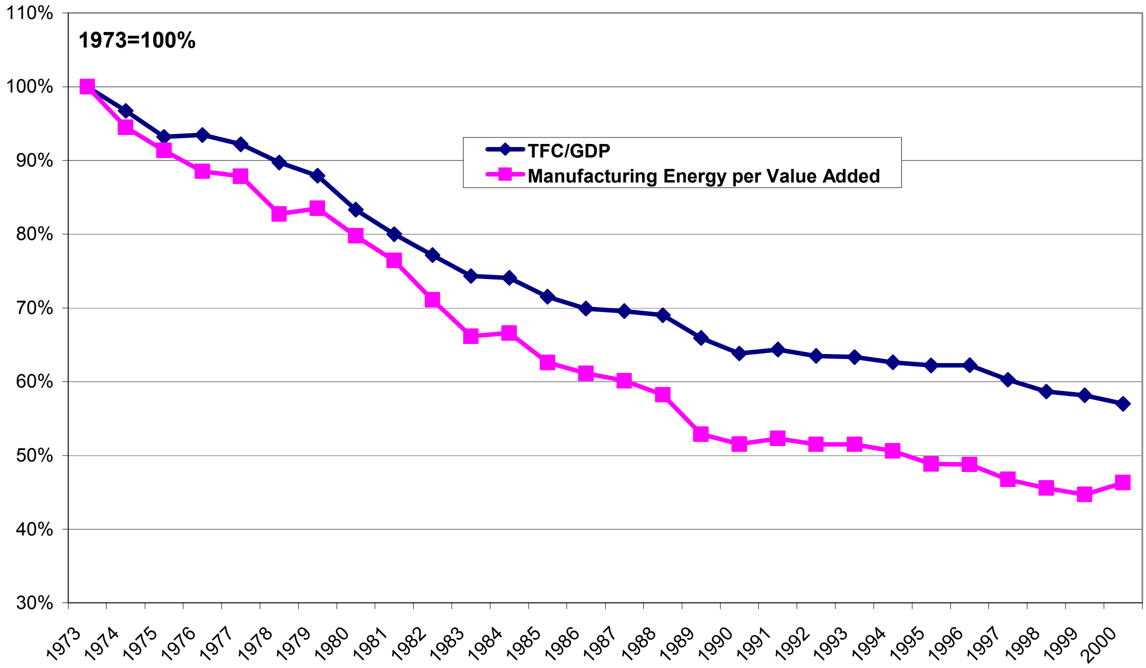
for which physical energy intensities are known. Refer to Farla (2000) and Worrell et al. (1997) for discussion of different intensity measures to analyse industrial energy use.

[2] In this paper this group of countries are denoted IEA-10 and includes Australia, Denmark, Finland, France, Japan, Italy, Norway, Sweden, the U.K., and the U.S.. For all these countries IEA has consistent time series with energy and value added data from 1973 through 1998.

[3] This paper uses the term "aggregate manufacturing energy intensity' when discussing trends in total manufacturing energy use per unit of manufacturing value added. This aggregate intensity is affected by both changes in sub-sectoral energy intensities and changes in the shares of total value added from each sub-sector.

presented in Figure 1 is needed. The subsequent sections of this paper illustrate how we can use data from IEA's work on energy indicators to better understand the effects changes in structure and intensities have had on manufacturing energy use. As a starting point for this discussion the next section presents trends in manufacturing output, measured as value added, which is an important driver of overall manufacturing energy use.

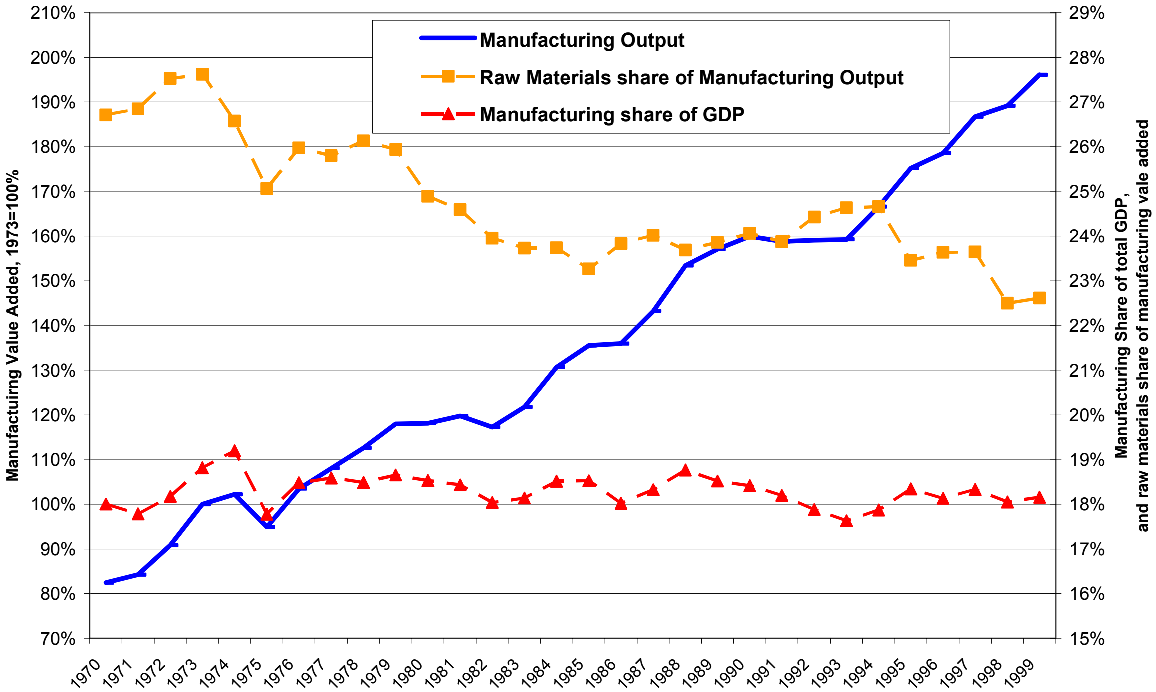
Figure 1. IEA-10 Total Final Energy Consumption (TFC) per GDP and Manufacturing Energy Use per unit of Manufacturing Value Added (1973=100%)



Manufacturing Output

IEA-10 manufacturing value added increased almost 90% between 1973 and 1998, 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. For most countries, the recessions affected the manufacturing sector relatively harder than other sectors of the economies. This development is also illustrated in Figure 2, where the manufacturing share of total GDP is plotted on the right axis.

Figure 2. Manufacturing Output, Manufacturing Share of GDP, and Raw Materials Share of Manufacturing Value Added; Aggregated Trends for 10 IEA 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 IEA-10 returning almost to the same level in 1989 as in the early 1970s before the recession of the early 1990s reduced its share again. All countries studied here experienced reductions in their manufacturing GDP shares in the years following 1990, which confirms the trend seen during the previous recessions. However, since 1993 manufacturing production has increased relative to GDP, bringing the share up to almost the same level as in the beginning of the 1970s. Thus, for this group of countries as a whole there is no evidence that manufacturing production has become less important in generating economic growth.

Interestingly, the share of energy intensive raw materials in manufacturing output had a similar development as the manufacturing GDP share (see Figure 2). This share also fell after both oil price shocks and recovered, or at least stabilised, in the immediate years after the recessions. However, after the recession following 1990, production of raw materials actually increased relative to the lighter industries. Then, since 1994 the share of raw materials in manufacturing has declined by 2 percentage points, which accounts for roughly half of the total decline in this share between 1973 and 1998. This reduction represents only a modest long-term reduction in the importance of energy-intensive manufacturing. In fact, statistics for individual countries show that the share of energy intensive raw materials in total manufacturing in 1998 exceeded the share in 1973 in all countries but Finland, Japan, and the U.S. Thus, outside these countries, IEA economies have not become significantly less dependent on raw materials in their manufacturing production since the first oil price shock in 1973. However, there have been significant changes to the mix of products *within* the production of raw materials. This can be expected to have an important impact on manufacturing energy use since these energy-intensive industries typically have large variations in energy use per unit of output. The larger the gap in energy intensities among different manufacturing branches, the greater the impact of shifts in the mix manufacturing output on total energy use over time. The next section of this paper discusses how these structural changes and changes in energy intensities have affected manufacturing energy use over time.

Impact of Structural Changes and Intensities

Following changes in intensities over time is of key policy interest because of their relationship to changes in energy efficiency. However, at the aggregate sectoral level, structure plays an important role. Consider an example where a country increases it's share of output from "other manufacturing" at the expense of ferrous metals. Since each dollar generated in the former sector requires one tenth or less of the energy input than ferrous metals, a small reduction in the share of ferrous metals will yield a significant reduction in the aggregate manufacturing energy intensity.

To demonstrate the impact of structural changes in manufacturing industry and the insights from using more disaggregated information, consider the results of a decomposition analysis for selected IEA countries shown in Figure 3.

The first two bars in the figure show average annual percentage changes in actual energy use and real value added between 1982 and 1998. All countries experienced growth in total value added during this period. Except for the UK, all countries also saw growth energy use in manufacturing, although at a slower rate than growth in output. This means that aggregate energy use per real manufacturing value added ("actual/output") fell in all countries. In some countries the decline in this indicator was significant, Japan, the US and the UK all achieved between 2 and 3 percent average reduction per year. To what extent is this development driven by energy efficiency improvements and to what extent is it a result of structural changes? To better separate between these two elements more disaggregated data were analysed. The fourth bar in Figure 3 represents the impact from of structural changes on manufacturing energy use, expressed as annual percentage change. To calculate the structural change effect, energy intensities for each of the seven subsectors are held constant and only the shares of value added among subsectors are varied. Similarly, the effect of changes in energy intensities, adjusted for these structural changes, is calculated by holding the subsectoral shares of output constant and while varying the subsectoral intensities (fifth bar in Figure 3).

The results show that indeed, structural changes have had an important impact on manufacturing energy use in especially Japan, the US and Norway. In the two former structural changes reduced energy use by around 1 percent on average per year. In Norway on the other hand, the industry moved towards a more energy intensive structure, driving up energy demand by 1.3% per year. If the structural changes are accounted for, the disaggregated energy intensity effect reduced manufacturing energy use by a little more than 2% per year in Japan, 1.3% per year in Norway and 1.2% in the US. In other words, the entire difference in the development of the aggregate intensity ("actual/output") between Norway and the US (0.2% annual decline vs. 2.3 %), can be explained from differences in structural changes. This demonstrates how misleading using aggregated data can be when analysing energy efficiency developments.

Figure 3. Changes in Manufacturing Energy Use 1982-1998
(Impact of Changes in Structure and Energy Intensities)

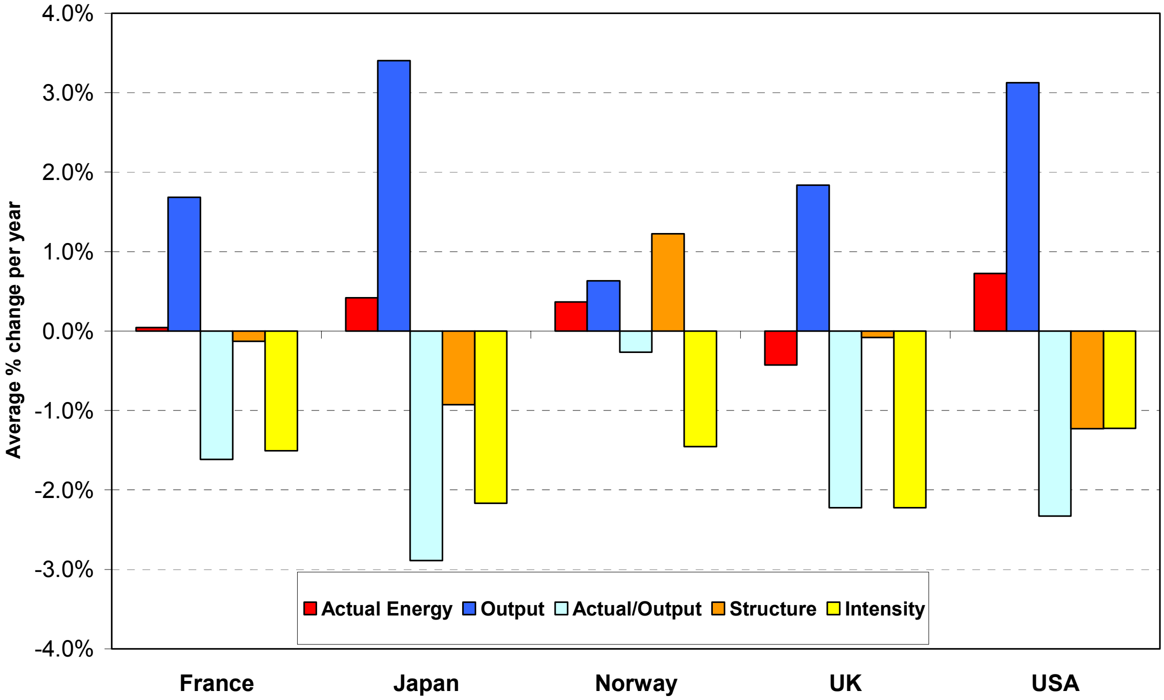
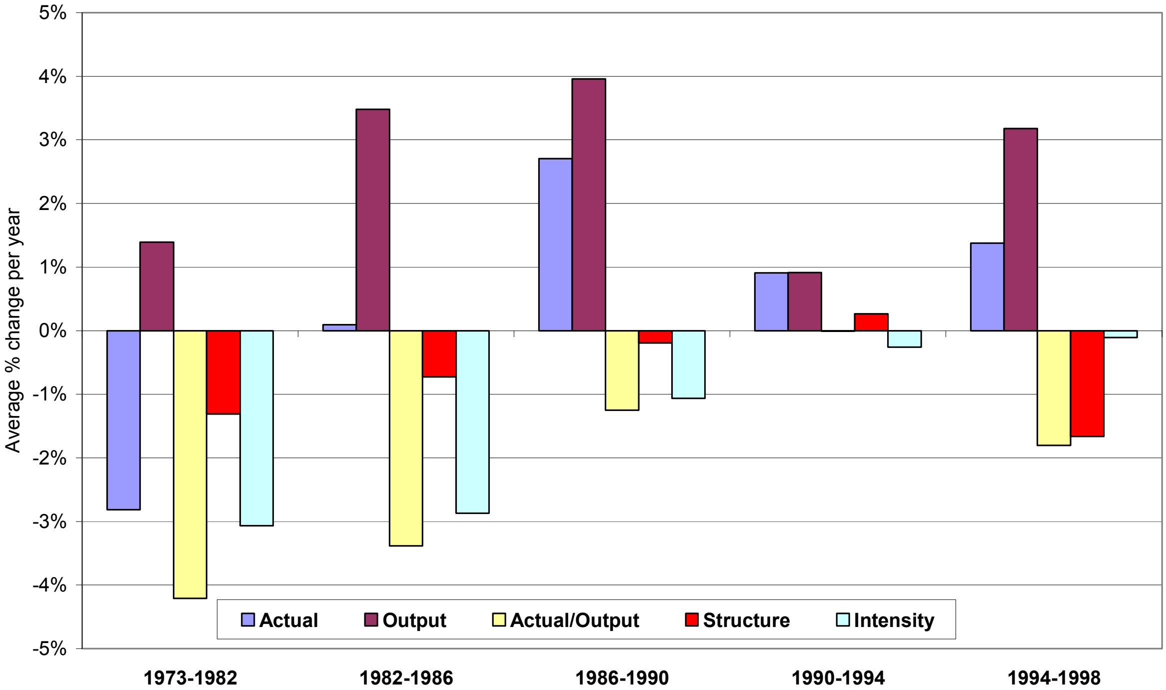


Figure 4 shows changes in the same factors for IEA-10 over five periods. Between 1973 and 1982 actual energy fell by almost 3% per year, while value added averaged a 1.4% annual growth. This led to a decline in aggregate intensity of a little more than 4% per year, but as manufacturing structure as a whole became less energy intensive, the structure-adjusted intensities fell by less, about 2.3% on average per year. A similar pattern emerges between 1982 and 1986. However, during this period increasing output largely offset the downward effect on energy use stemming from intensity and structural changes, with no net change in energy use as a result. Over the following four years, the rate of decline in energy intensities fell to only 1% while the effects of structural changes were negligible. Thus strong growth in output led to an increase in energy consumption averaging 2.7 % per year. Between 1990 and 1994 energy consumption was restrained primarily by economic recession. Energy use and output moved in parallel at a rate of almost 1% per year. Over these four years there was a small impact on energy use from structural change, primarily due the production chemicals and paper and pulp which outpaced the average growth in total manufacturing. Adjusted for these structural changes, the fall in energy intensity averaged only a modest 0.3% per year between 1990 and 1994.

Figure 4. Changes in Manufacturing Energy Use for IEA-10 (Impact of Changes in Structure and Energy Intensities)



Over the next four years the picture changed; manufacturing production picked up and grew at an average annual rate of 3.2%, while energy use only increased by 1.4% per year. However, as most of the manufacturing growth came in less energy intensive industries, such as the production of electronics, the industry structure became significantly less energy intensive during this period. This structural change affected energy use in IEA-10 even more than structural changes did over the 1973-1982 period. In fact, almost all the decoupling between energy use and output during 1994 and 1998 can be explained by structural changes. The energy intensity effect only reduced manufacturing energy use by 0.1% annually over this period, which is less than in any of the other periods shown in Figure 4.

This may point to that the strong reduction in energy use per economic output that the US and other IEA countries saw during the last half of the 1990s may be more a result of structural changes than of improved energy efficiency. Investigating results for individual countries indicates that this was indeed the case most places. Table 1 shows that all countries experienced a relatively strong growth in output between 1994 and 1998, while energy use, also in all cases, grew less than output, i.e. aggregate intensity fell. However, in all countries but Denmark, the structure became less energy intensive. This resulted in that in most cases the decline in the structure adjusted energy intensity was modest compared to earlier periods. Structural changes also played an important role in reducing manufacturing energy use between 1973 and 1986 for all countries but Australia and Norway, which benefited from access to inexpensive domestic energy sources. Between 1986 and 1994 the picture was more mixed; countries with already a high share of raw materials in their production, Norway, Sweden, Finland and Australia, saw an increase in the relative shares of energy intensive industries, while in the larger economies, the US, the UK and Japan, there was a small shift away from these industries. In total for IEA-10 the net effect of structural changes was zero between 1986 and 1994, in stark contrast to the next four years, when structural changes pushed up manufacturing energy use by on average 1.7% per year, all else being equal.

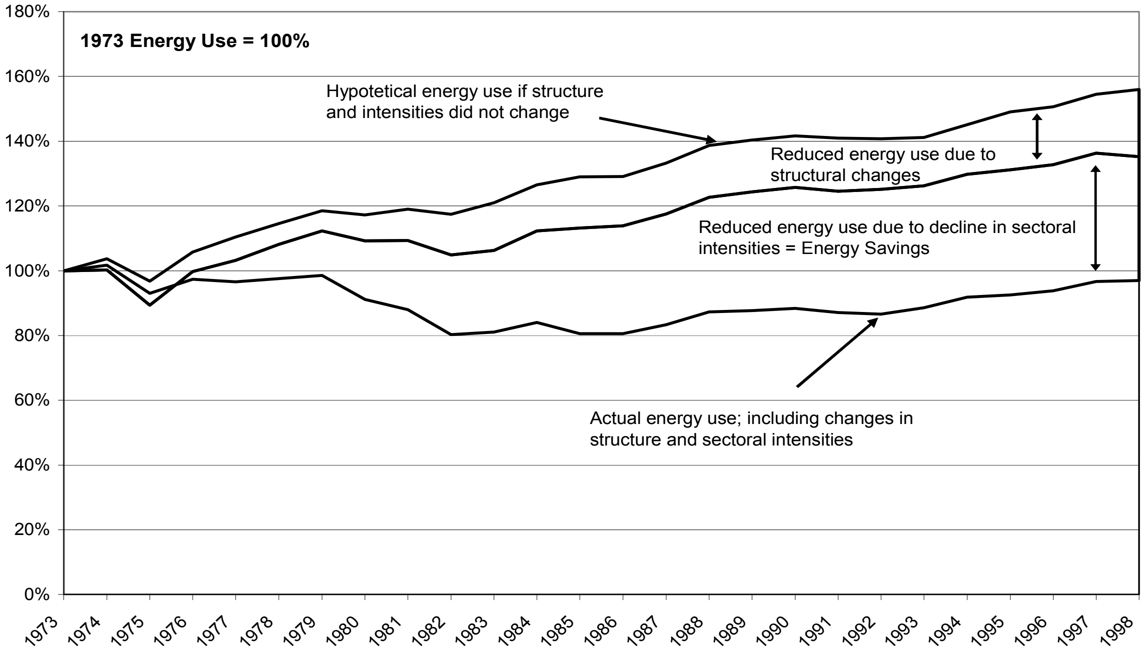
Table 1. Average Annual Rates of Change in Manufacturing Energy Use, Output, Structure, and Energy Intensity

	Energy Use			Output			Structure			Energy Intensity		
Country	1973-1986	1986-1994	1994-1998	1973-1986	1986-1994	1994-1998	1973-1986	1986-1994	1994-1998	1973-1986	1986-1994	1994-1998
Australia	0.3%	2.0%	1.7%	0.8%	1.9%	2.4%	0.8%	0.9%	-1.1%	-1.1%	-0.8%	0.4%
Denmark	-2.5%	0.7%	0.8%	2.1%	0.1%	2.1%	-0.3%	-0.1%	1.0%	-4.9%	0.8%	-1.6%
Finland	1.8%	2.6%	1.5%	2.8%	2.4%	7.2%	-0.1%	1.0%	-3.0%	-0.9%	-0.8%	-3.6%
France	-2.7%	1.0%	1.4%	1.0%	1.3%	3.4%	-0.5%	0.0%	-0.7%	-3.8%	-0.5%	-1.1%
Italy	-2.2%	1.5%	1.5%	3.2%	2.1%	2.0%	-0.1%	0.3%	-0.1%	-6.4%	-0.9%	-0.3%
Japan	-1.7%	1.7%	0.5%	3.6%	2.9%	1.3%	-1.8%	-0.1%	-1.9%	-3.7%	-1.2%	1.4%
Norway	0.1%	0.3%	0.4%	0.2%	0.3%	2.4%	0.5%	1.5%	-1.7%	-0.9%	-1.6%	0.3%
Sweden	-1.4%	0.0%	2.2%	0.9%	1.4%	5.7%	-0.3%	1.6%	-4.0%	-1.9%	-2.9%	1.3%
UK	-3.2%	-1.2%	-0.5%	-0.6%	1.8%	0.9%	-0.4%	-0.3%	-0.3%	-2.3%	-2.6%	-1.2%
US	-2.1%	2.4%	1.8%	2.3%	2.6%	4.5%	-1.3%	-0.1%	-2.5%	-3.5%	-0.1%	-0.1%
IEA-10	-1.9%	1.8%	1.4%	2.0%	2.4%	3.2%	-1.1%	0.0%	-1.7%	-3.0%	-0.7%	-0.1%

How much did structural changes and falling energy intensities reduce energy in IEA-10 between 1973 and 1998? In Figure 5 the lower curve represents actual IEA-10 energy use, including the effect of changes in both structure and in energy intensities. The level of the middle curve is calculated by adding the energy savings from changes in energy intensities for each year to actual energy use. Finally, the upper curve represents the hypothetical energy use that would have occurred if no changes in structure or energy intensities had taken place. This curve is calculated by adding the changes in energy use from structural changes for each year to the level of the second curve.

The difference between the upper and the middle curve illustrates the reduction in manufacturing energy use due to structural changes. As discussed above, the IEA-10 structure gradually became less energy intensive until the end of the 1980s, i.e. the gap between the two upper curves in Figure 5 widens. The modest shift toward more energy-intensive industries that occurred after 1990 can be seen from the slight closing of the gap between the curves, before structural changes again start to push down energy use. By 1998 the difference between the two upper curves corresponds to around 21% of 1973 actual energy use (or 23% of 1998 actual energy use). Similarly, declining energy intensities led to approximately 38% savings of manufacturing energy use between 1973 and 1998, according to the method used here. Clearly, energy intensities led to more restraint in energy-use growth than did structural changes, but structural changes still accounted for more than a third of the total energy savings compared to the baseline aggregate intensity.

Figure 5. Hypothetical Energy Use Without Savings from Reduced Energy Intensities and Structural Changes; Hypothetical Energy Use with Savings from Structural Changes; and Actual Energy Use Including all Savings



Conclusions

The results of the decomposition analysis presented in this paper show that structural changes have significantly affected energy use in manufacturing between 1973 and 1998. In most countries, particularly the U.S. and Japan, the mix of manufacturing output moved away from energy-intensive products, leading to lower manufacturing energy use, all else being equal. In a few countries, however, the manufacturing structure became more energy intensive and thus drove up energy use over this period. For the group of ten IEA nations, the net effect of structural changes accounted for more than a third of the reduction in total manufacturing energy use per unit of output between 1973 and 1998. The rest of the reductions in this period can be explained by falling energy intensities in individual manufacturing branches. The fall in these intensities can to some degree be attributed to improved energy efficiency. Contrasting post-1986 with earlier years shows that the rate of energy intensity decline in manufacturing slowed in most countries.

Examining recent trends through 1998 indicates that, while very little total change in energy intensities took place most places, significant structural shifts occurred that reduced aggregate manufacturing energy use per unit of output. That shift was in many countries led by rapid output in electronics and electronic equipment industries. This can be related to changes in economic activities due to the so-called information economy, e.g. more production of information-intensive goods like electronics, with lower energy requirements per unit of value added than both raw materials and more traditional products, such as white goods or transportation equipment.

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