Decomposing Changes in the Energy Demand of UK Manufacturing

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Abstract: Over the period 1990-2007 the energy demand of UK manufacturing has fallen. A decomposition analysis was conducted to identify the effects of changes in output, structure and energy intensity on the changing energy demand. It was found that a falling energy intensity (indicating improving energy efficiency) was the principle reason for the fall in energy demand. As the UK manufacturing sector is so broad in its uses of energy, it was split into an energy-intensive (EI) and a non-energy-intensive (NEI) sub-sector to better understand the improvement in energy efficiency. The NEI sub-sector made much greater relative reductions in energy intensity in comparison to the EI sub-sector. Previous studies indicate that the EI sector may have made larger improvements in energy intensity in the period between 1973 and 1990 and this may be the reason for the limited improvement seen here. Neither energy price nor production growth appears strongly correlated with the improving efficiency over the period 1990-2007.

Keywords: Decomposition, Efficiency, Energy, Intensity, Industry, Manufacturing.

1. Introduction

Reducing dependence on fossil fuels as an energy source protects against the dangers of both climate change and energy security. Decreasing energy demand through management and efficiency measures is often seen as the most technologically simple and economic option available, to achieve a reduction in fossil fuel use [1-3]. The UK manufacturing sector is a significant user of energy, accounting for approximately 20% of the UK's final user demand [4], reducing the energy use of manufacturing is important in reaching government targets. Industry is however difficult to analyse due to the large variability in the ways energy is used within the sector.

Past trends in energy use can help us better understand the current situation and influence future decisions aimed at reducing energy use. Changes in energy demand over time can be the result of a number of factors. Decomposition analysis methods can be used to analyse manufacturing, by examining the contribution of changes in industrial structure, output and energy intensity to changing energy demand [5]. The isolated effect of changing energy intensity is a useful measure of energy efficiency. It can therefore be used to examine improvements made and the success of energy policy.

A study of the Netherlands [6] examines the industrial sector over the years 1988-1999. Industry is split into an energy-intensive and a non-energy-intensive sub-sector. Decomposition analysis is performed on the non-energy-intensive sub-sector, which was found to have made no improvement in energy efficiency over the years studied. Decomposition studies of the UK industrial sector have been undertaken by previous studies [7-11] and cover the time period from the late 1960s, to the early 1990s.

The aim of the current work is to decompose changes seen in UK manufacturing energy demand over the recent time period. The manufacturing sector will be split, in common with the Dutch study above [6], into an energy-intensive (EI) and a non-energy-intensive (NEI) sub-sector, with a decomposition analysis undertaken of each. The EI sub-sector is expected to have stronger drivers for improving energy efficiency due to the greater possible financial gain for this sub-sector in reducing energy use and as the EI sub-sector is a target for energy policy in the UK. However previous studies have found that there is no simple link between energy price and efficiency improvements, indicating that financial gain is not the only motivation for increased efficiency [8, 9]. Other factors such as output growth and investment rate can have an important effect on

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efficiency improvements. It will therefore be of interest to see how the EI and NEI sub-sectors differ in efficiency improvements made.

2. Methodology and datasources

2.1 Defining relevant measures

The manufacturing sector examined here is defined by SIC codes 15-37, excluding the sub-sector defined by SIC 23 (Manufacture of coke, refined petroleum products and nuclear fuel), full details of SIC classification are available in [12]. Energy demand is measured in terms of higher heating value (HHV) and primary energy. Data on final energy demand is obtained from the Digest of United Kingdom Energy Statistics (DUKES) [13] and Energy Consumption in the UK (ECUK) [13, 14]. Factors for the conversion to primary energy are those used in the Climate Change Agreements (CCAs) [15]. Electricity conversion factors are averaged over each studied period so improvements in the efficiency of electricity generation are not seen as improvements by the end user. There is no differentiation here between electricity supplied by combined heat and power plants and from the national grid. Value of production is used as the measure of manufacturing output as it better represents the true physical output of a sector than value added [16], being less likely to exaggerate changes in real output. The Index of Production (IoP) [17] is used with economic output data in current terms for 2005, taken from the Annual Business Inquiry (ABI) [18] to calculate value of production at constant 2005 prices. Aggregate energy intensity is defined as energy demand/output. Data on costs and number of enterprises in each sub-sector are taken from the ABI [18], energy price data are from the Quarterly Energy Prices publication [19].

2.2 Defining energy intensive industry

Various methods of defining an EI and NEI sub-sector within manufacturing are discussed by [6]. This paper follows the recommendation of [6] in defining a sub-sector as EI or NEI based on the values of a number of criteria, here these criteria and the values for the split between EI and NEI sub-sectors differ slightly to the previous study [6]. The criteria used are:

1. Aggregate energy intensity
2. Proportion of total costs represented by energy and water costs[1].
3. Energy demand per enterprise.

If a sub-sector had a sufficiently large value for any of the above criteria results it was defined as EI. Values should therefore represent a strong financial driver to explore and implement energy saving options in comparison to the remainder of the manufacturing sector. Values for the split between the EI and NEI sub-sectors are set as one and a half times the figure for the manufacturing sector for criteria 1 and 2. For criteria 3, due to a greater variation in values, and as it is seen as a weaker driver a limit of 100TJ/enterprise is used. The values used to define the sub-sectors as EI or NEI are the mean of the results for the years 2002-2006, after removing the highest and lowest values.

2.3 Decomposition analysis

There are a number of techniques available for decomposition analysis, a useful guide to the various options is given by [20]. The log mean Divisia index method I (LMDI I) is used here, it was first introduced by Ang, Zhang and Choi [21]. The method is perfect in decomposition, with no residual term, it is recommended for general use based on theoretical foundation, adaptability, ease of use and ease of result interpretation [20].

The methodology shown here is adapted from [22]. Additive decomposition analysis is used, where by the total change in energy demand (ΔE_{tot}), over a time period (0 to T), is a sum of the changes due to changes in production volume[2] (ΔE_{pdn}), changes in structure (ΔE_{str}), and changes in intensity (ΔE_{int}).

$$\Delta E_{tot} = E^T - E^0 = \Delta E_{pdn} + \Delta E_{str} + \Delta E_{int}, \qquad (1)$$

For i sub-sectors of industry, total energy demand can be given as,

$$E = \sum_i E_i = \sum_i Q \frac{Q_i}{Q} \frac{E_i}{Q_i} = \sum_i Q S_i I_i, \qquad (2)$$

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[1] Ideally only energy costs would be used, however, due to restrictions in the data set used [18], energy and water costs were grouped.

[2] The term output is also used to refer to production volume.

where Q is output. S_i (=Q_i/Q) and I_i (=E_i/Q_i) are, respectively, the activity share and aggregate energy intensity of sector i. The components of change in (1) are calculated from,

$$\Delta E_{pdn} = \sum_i L\left(E_i^T, E_i^0\right) \ln \frac{Q^T}{Q^0}, \qquad (3)$$

$$\Delta E_{str} = \sum_i L\left(E_i^T, E_i^0\right) \ln \frac{S_i^T}{S_i^0}, \qquad (4)$$

$$\Delta E_{\text{int}} = \sum_i L\left(E_i^T, E_i^0\right) \ln \frac{I_i^T}{I_i^0}, \qquad (5)$$

where,

$$L\left(E_i^T, E_i^0\right) = \frac{E_i^T - E_i^0}{\ln E_i^T - \ln E_i^0}. \qquad (6)$$

The change due to intensity is a good measure of energy efficiency, such that as intensity drops, efficiency increases.

2.4 Timescale and disaggregation level of analysis

Some studies have found the level of disaggregation used in a decomposition analysis can significantly effect results [23], and structural change can be underestimated if analysis is not undertaken at a high enough level of disaggregation [9]. So initially the analysis was conducted at the highest disaggregation level possible, with the datasources utilised. This resulted in 70 sub-sectors of manufacturing (both for defining the EI/NEI split and the decomposition analysis). The time period that could be analysed at this level of disaggregation was however limited. An analysis was also carried out at the 2-digit SIC level (21 manufacturing sub-sectors). It was found that there were not significant differences between results using the different levels of disaggregation. The more aggregated results, at a 2-digit SIC level, were therefore used as a wider time period could be analysed.

The decomposition analysis covered the time period 1990-2007. Due to methodological changes in the collection of energy data [13], over the periods 1995-1996, 1998-1999 and 2000-2001, analysis could not span all years. Because of a lack of output data, the recycling sub-sector (SIC 37) could not be included in the decomposition analysis.

3. Results

3.1 Defining energy-intensive industry

There are nine sub-sectors classified as EI, these sub-sectors are labelled in Fig. 1. To be defined as EI a sub-sector requires an aggregate intensity greater than 6.46MJ/£, and/or energy and water costs greater than 3.3% of total costs, and/or energy demand per enterprise greater than 100TJ. Note the logarithmic scales on Fig. 1. There is an order of magnitude variation across the manufacturing sector for each of the three criteria plotted (the logarithmic scale does not apply to the area of the data points). The EI sub-sector is responsible for approximately 65% of energy demand, whereas the NEI sub-sector contributes approximately 65% of economic output. This leads to an aggregate intensity in the EI sub-sector of approximately four times that in the NEI sub-sector.

3.2 Decomposition analysis

Decomposition analysis for the manufacturing sector was undertaken at two levels of disaggregation: a 2-digit SIC level (21 sub-sectors), and by splitting into just the EI and NEI sub-sectors. The results are shown in Fig. 2. The results are indexed to the energy demand in 1990 and show cumulative additive change. The periods for which methodological change occurred in the data, preventing analysis, are indicated by dotted lines. As the results are stagnant during periods of methodological change the total changes over the period 1990-2007 may differ from than those presented here.

It can be seen in Fig. 2 that structural change has had little influence on energy demand. Manufacturing output has increased over the period studied, the reduction in output in the early 1990s was due to a recession in the UK. The reduction seen in energy demand, of 12% between 1990 and 2007 is driven principally by a decrease in intensity.

The total change in energy demand and change due to output are independent of disaggregation level and therefore equal in A and B of Fig. 2. The other results are also similar between the two disaggregation levels.

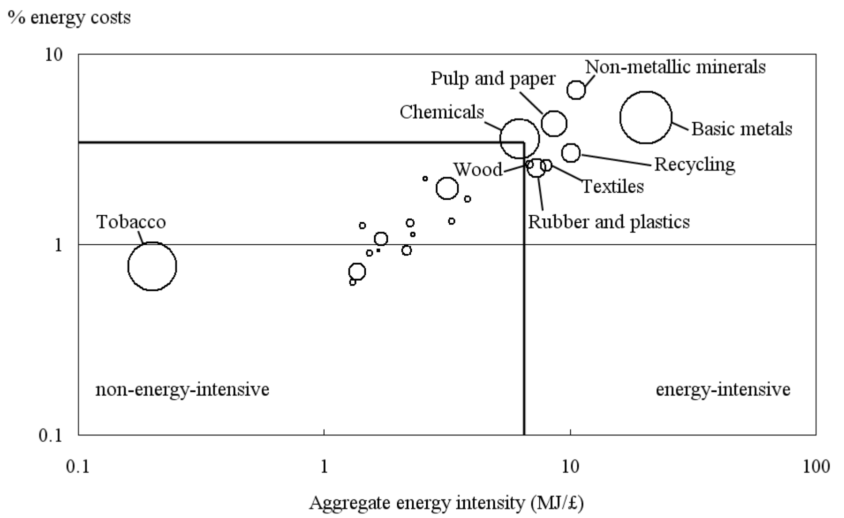

Fig. 1 UK industrial aggregate energy intensity, and percentage of total costs: represented by energy and water, and energy use per enterprise (represented by area of data points). Manufacturing split at the 2-digit SIC level, 2002-2006.

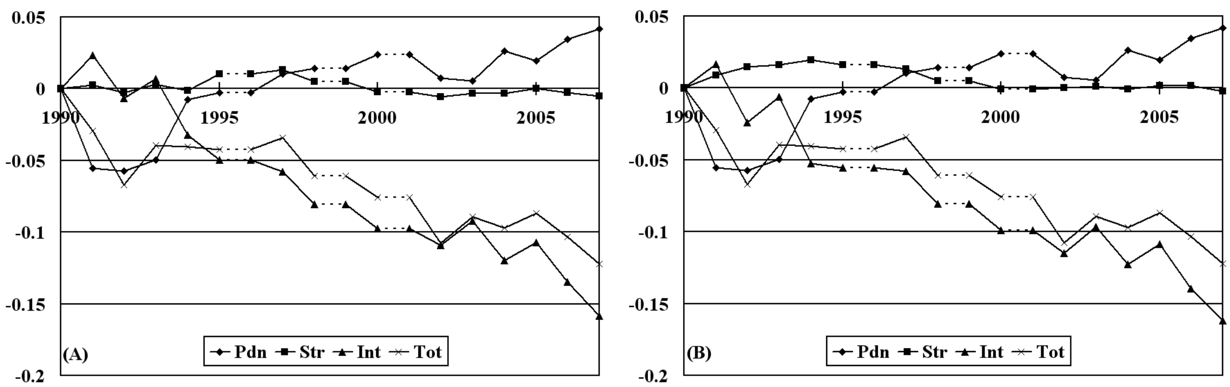

Fig. 2 Decomposition of the UK manufacturing sector showing the change in energy demand (Tot) and the contributions due to changes in output (Pdn), structure of the sector (Str), and intensity (Int). (A) Disaggregation at the 2-digit SIC level. (B) Disaggregation into just two sub-sectors, EI and NEI.

The EI and NEI sub-sectors are decomposed independently in Fig. 3. The changes are indexed to the energy demand in 1990, the baseline, for each sector. Much greater relative reductions in the energy demand of the NEI sub-sector have been made. This is predominantly due to the falling energy intensity in the NEI sub-sector. Over the period 1990-2007, if structure and output had been constant in each of the sub-sectors, then EI energy demand would have fallen just 7% due to the intensity effect. This contrasts with 32% in the NEI sub-sector.

The relationship between energy price for the manufacturing sector and falling intensity is shown in Fig. 4. Energy price does not appear to have an effect on the intensity. The intensity decreases at a fairly constant rate for manufacturing, (as it does in both the EI and NEI sub-sectors, when examined separately as shown in Fig. 3) and is unaffected by the fluctuations in energy price. Energy prices can also influence the structure of industry, causing a move to less energy-intensive industries, this was seen in the years following the first oil crisis [9]. However, for the present study, no significant structural change has been observed (Fig. 2 and Fig. 3). The most significant change in energy price occurred since 2004. It may take a few years of sustained high prices for companies to react, and the effect of increasing energy prices may therefore not yet have been seen.

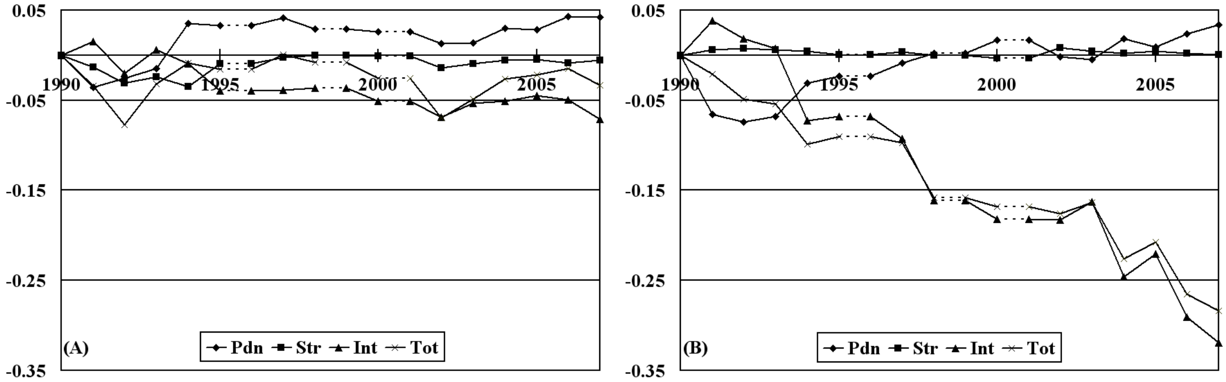

Fig. 3 (A) Decomposition of the UK EI sub-sector. (B) Decomposition of the UK NEI sub-sector.

If manufacturing output rises, investment in new technology usually rises as new plant and equipment are purchased, this tends to increase efficiency. Fig. 2 and 3 show some correlation in this regard. As production fell in the early 1990s, intensity was fairly stagnant; as output increased intensity fell. However, the NEI sub-sector shows less relative growth in output and yet the largest relative intensity improvements. If year-on-year changes in output and intensity are examined there is some correlation (see Fig. 5). Nevertheless, this correlation is much weaker when both the EI and NEI sub-sectors are examined independently. It cannot therefore be said that there is a good correlation between intensity drop and production increase.

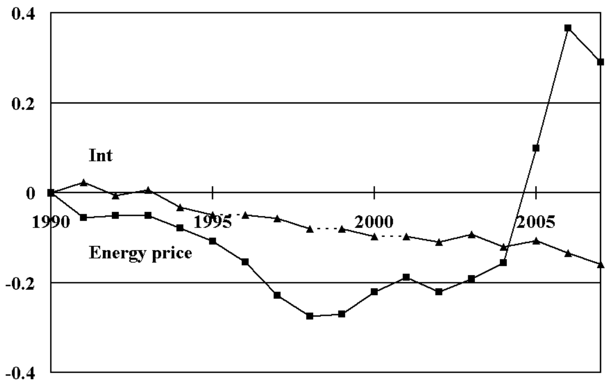

Fig. 4 Total energy price for the UK industrial sector (in real terms, including the CCL) and change in energy demand due to intensity, from Fig. 2 (A). Both indexed to 0 in 1990.

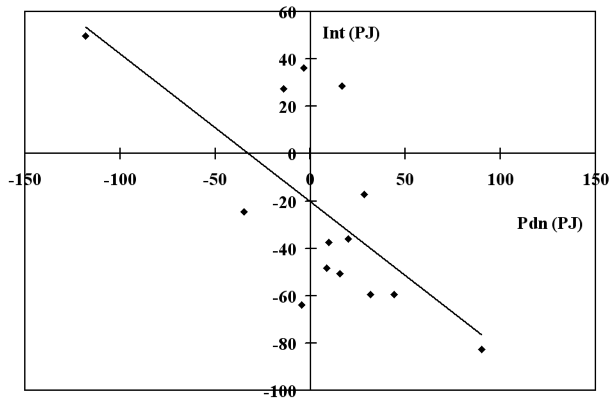

Fig. 5 Correlation between increased production and falling intensity, for the UK manufacturing sector: 1990-2007.

A changing fuel split could effect efficiency improvements. Electricity can generally be used more efficiently than other fuels in terms of final demand, due to the higher level of control possible. However electricity will lead to a higher primary energy demand than the fossil fuel alternatives, due to generation inefficiencies[3].

Fuel splits for the UK EI and NEI sub-sectors are shown in Fig. 6. The changing fuel splits in the EI and NEI sub-sectors are not vastly different and are unlikely to be a significant reason for the difference in changes of energy intensity observed.

[3] Electricity can be generated by low or zero carbon technologies, and so a higher proportion of electricity use could lead to future reductions in fossil fuel use and associated emissions.

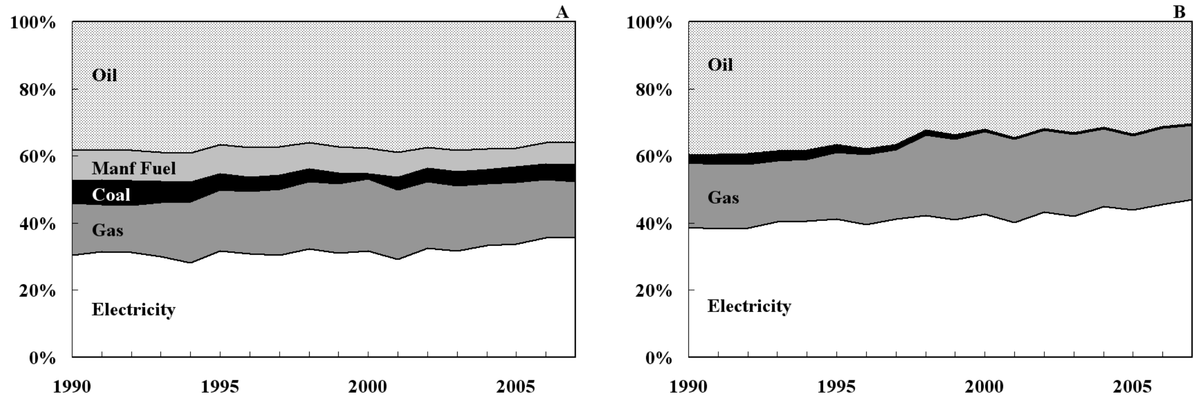

Fig. 6 UK fuel split for the EI sub-sector (A) and the NEI sub-sector (B).

4. Concluding remarks

The decomposition analysis undertaken with a disaggregation into only the EI and NEI sub-sectors yielded good agreement with those results using a higher level of disaggregation. This suggests that splitting UK manufacturing into just the EI and NEI sub-sectors characterises the sector well in this case.

It was found that the NEI sub-sector has made considerably greater reductions in energy demand due to improved efficiency (32%) relative the EI sub-sector (7%). Interestingly much larger improvements are seen in the UK than in the NEI sub-sector in the Netherlands [6][4]. No strong link was found in the present study between either energy price or manufacturing output and the improved efficiency. A previous study [8] examined the link between price and efficiency for eight OECD countries. Efficiency was not found to increase more rapidly when energy prices were high. Greater gains were sometimes observed when prices were low. These low prices were typically coupled with higher industrial growth, and hence investment in new technology. However, the same study [8], also displayed a decoupling of output and intensity improvements in the UK over the period 1973-87. Efficiency improvements are not insensitive to price, but the relationship is not a simple one and other factors can be important. Price can also influence structure, high energy prices encourage a move towards less energy-intensive manufacturing [9]. But there is very little influence on energy demand due to structural change from the UK results analysed here. It is only since 2004 that energy prices have increased in real terms from the 1990 baseline. The effect of this price increase may yet be seen, due to a lag in the response of manufacturing.

It is useful to put the results obtained here in a broader historical context. Whilst the various studies examined use different decomposition methods, disaggregation level, and have differing definitions of 'industry' or 'manufacturing', general trends may be extracted and will help to frame the present results. Since decomposition analyses were first conducted for UK manufacturing, in the late 1960s, intensity improvements have induced much greater reductions in energy demand than structural changes, [7, 8, 11]. The possible exception to this observation is during the period following the first oil crisis (1973-1978), when structural and intensity changes had similar effects on aggregate intensity [9]. All the previous studies [7-11] show continued improvements in efficiency over time, as would be expected. Nevertheless the sub-sectors in which these improvements were made is important. From 1968-1978 a previous study [9] found greater efficiency improvements generally occurred in those sub-sectors classed here as EI than in industry as a whole. A split into an energy-intensive and an "other" group of

[4] The NEI sector is defined slightly differently in the two studies, and therefore results are not directly comparable. However the difference is striking enough to still be indicative of a substantial difference in results.

industry was made by [10], in a broadly similar manner to that adopted here. Decomposition analysis was not undertaken, although the aggregate intensity was analysed. It was found that from 1973-1980 the energy-intensive group made relative year-on-year improvements in aggregate intensity three times those of the “other” group. From 1980-1988 the relative improvements seen in the two groups were almost equal.

Studies for the time period previous to that covered here indicate that the EI sub-sector may have made greater improvements in efficiency from the first oil crisis until the late 1980s. The greater relative improvements in efficiency by the NEI sub-sector, in the period 1990-2007, may therefore be as there were more “low hanging fruit” still available for the NEI sub-sector over this period. Larger improvements had perhaps already been made in the EI sub-sector, thereby making further improvements more difficult. Whether the improvements in energy efficiency seen in this study can be maintained or surpassed in the future is an important consideration and one that demands more attention than can be given here. However some sources indicate large improvements in the energy efficiency of manufacturing are still possible [24, 25].

Further analysis may investigate the effect sub-sectors at the 2-digit SIC level have on results to see if there are individual sub-sectors causing a substantial proportion of the changes in energy intensity observed here. This could indicate those sub-sectors to focus on in future. A decomposition analysis of carbon emissions would also be a useful exercise to compare savings delivered by improved industrial efficiency, to those achieved through fuel switching and improved efficiency of electricity generation.

Increasing energy prices through policy is a difficult balancing act. Price can act as a stimulus for increased efficiency but, if prices are too high, can lead to a lack of growth and stifle investment in efficient technology. High energy prices can also cause structural change and carbon leakage into areas of the world with lower prices. Price rises are also not the only way to stimulate efficiency improvements. Schemes that both supplement the cost, and encourage development of more efficient equipment can also be effective. Output growth can help this improvement in efficiency through the purchasing of new equipment, although output growth also increases energy demand. In order to reach future emission targets, consumerism and output growth may need to be curtailed and so cannot be relied upon to provide the required efficiency improvements.

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