The relative importance of technical and behavioural trends in electricity consumption by domestic appliances

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1. SYNOPSIS

This paper discusses technical, demographic and behavioural variables essential in developing baseline scenarios for assessing the impact of policy aimed at reduced environmental impact.

2. ABSTRACT

In the UK electricity consumption by domestic appliances has doubled in the last two decades. Appliances are the fastest growing source of carbon dioxide emissions outside the transport sector. Policy intervention aimed at market transformation is currently being designed at the EU and national levels to reduce electricity consumption and associated emissions.

The total energy consumption from a particular end-use is a combination of appliance ownership levels, technical efficiency and behavioural patterns. In most countries, changes in ownership levels over time are known. However, the underlying rates of technical improvement and changes in patterns of use are less well researched.

Understanding these trends is essential for policy aimed at market transformation. This understanding provides a baseline projection from which to assess the actual savings from policy intervention. In addition, it shows how some changes in use or purchasing patterns may wipe out savings made from improvements in technical efficiency. The major focus to date has been on the cold appliances (refrigerators, freezers and fridge-freezers) and wet appliances (washing machines, tumble dryers and dishwashers), and these are the subject of this paper.

3. INTRODUCTION

Recent work by the DECADE (Domestic Equipment and Carbon Dioxide Emissions) team at the University of Oxford demonstrates that electricity consumption from domestic appliances in Great Britain (ie UK excluding Northern Ireland) has doubled in two decades from 30 TWh to over 60 TWh (Figure 1). Appliances are the fastest growing source of carbon dioxide emissions outside the transport sector.

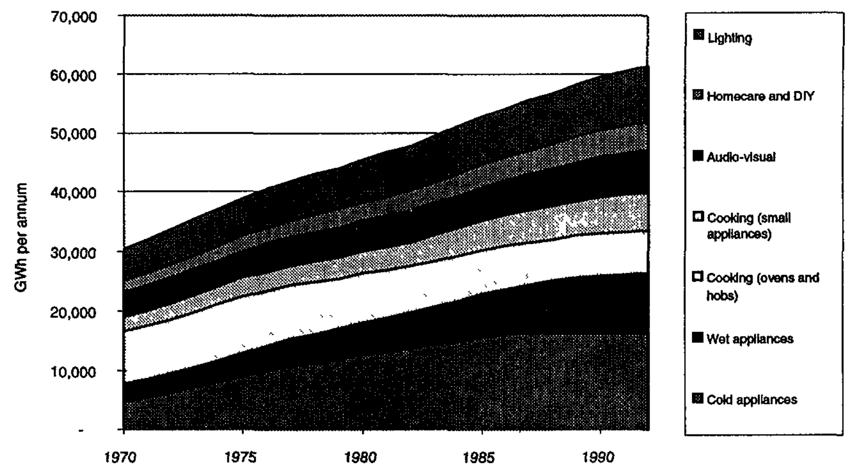

Figure 1 Total electricity consumption by domestic appliances, Great Britain 1970-1992
Source: DECADE (1995)

Detailed disaggregation of trends has not been seen as necessary while there has been little or no policy intervention to reduce appliance consumption. However, recently:

- the EU introduced energy labels for the cold appliances (refrigerators, freezers and fridge-freezers) on January 1st 1995, with labels for washing machines and tumble dryers to follow in January 1996 (CEC 1992, CEC 1994). Labels for dishwashers are expected to follow;
- minimum standards for energy efficiency are under discussion, prompted at the national level by the Danish and Dutch governments, but taken up at the EU level (GEA 1993, GEA 1994a, CEC 1995);
- in several EU countries, investment programmes (both rebates and technology procurement programmes) have focused on appliances; for example, Sweden (NUTEK 1993, NUTEK c1991), the Netherlands (Nieuwenhuyse 1994), and Germany (RWE Energie 1992). In the UK, under the supply price control introduced by the Electricity Regulator, the Regional Electricity Companies have an explicit obligation to explore and invest in demand side measures. Of the £100 million allocated for investment in the domestic sector between 1994 and 1998 (required to achieve savings of 5,000 GWh), a quarter has been earmarked for appliance programmes such as rebates and procurement (Offer 1994).

Most policy instruments (labels, standards, rebates and procurement) have been aimed at improving the technical efficiency of the average new appliance sold. In order to assess the actual energy savings, it is necessary to establish a baseline from which to estimate the potential savings from policy intervention, and a thorough understanding of technical and behavioural trends is helpful in establishing such a baseline.

Schipper and Meyers (1992) developed an overview of demographic, ownership and technical trends in domestic energy consumption. Work by DECADE and the Group for Efficient Appliances (GEA) has been focused on major energy consumers: more than 40% of the total consumption by appliances comes from the cold and wet appliances, and these thus form the focus of policy and of this paper.

4. DATA SOURCES

The energy consumed by an appliance nationally is affected by ownership levels, technical efficiency and behavioural patterns. The following trends are examined:

- social or demographic factors, such as increased number of households, and reduced family size,
- ownership levels as a percentage of households,
- changes in efficiency, size, and features of appliances reflecting a change in consumption under test conditions,
- changes in usage patterns of appliances which may only in part be a reflection of technical or demographic changes and may include a change in consumer choice: for example, an increased number of laundry washes per annum, a much greater volume of frozen space, and greater consumption of convenience foods.

In the UK, changes in ownership levels are relatively well known. Much of the total increase in consumption is due to increased ownership of appliances. However, the effect of demographics, technical and usage trends have offset or added to the total change in consumption, though the understanding of such trends is poor.

4.1. Demographic changes

Appliance consumption is affected by both increasing number of households and reducing household size. In the UK there are fewer six-or-more person households, and a large increase in one-person households: one-quarter of UK households are now one-person households. The effect on average household size is a decline from 3.1 in 1961 to 2.4 persons in 1993, or 0.7% pa. European average household size has declined at the same rate, but there is still a wide range between countries. Sweden has the smallest household size (2.15) and Ireland the largest (3.84) (Euromonitor data). Other EU countries have a still higher percentage of one-person households: 34% of German households and 33% of Danish households. Household size in the UK is expected to decline at a similar underlying rate at least to 2020 (Figure 2).

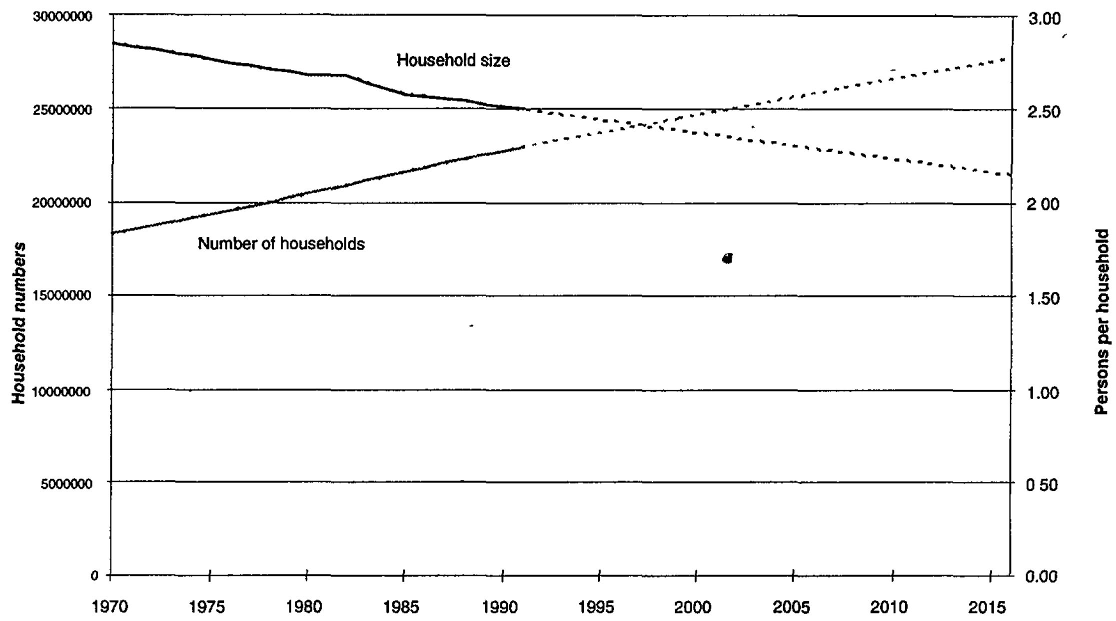

Figure 2 *UK Household numbers and household size to 1990 and forecast to 2016*
Source: Milne (1995) 1 and Social Trends (1995)

These demographic changes have several effects: first, an increasing number of households implies an increasing number of appliances even if household percentage ownership of appliances remains constant. Secondly, if the use of an appliance is proportional to household size, it might be expected that declining family size implies a reduction in the number of uses of appliance per annum, and for some appliances a reduction in the size of appliance bought.

In addition, four or five-person households are much more likely to own a washing machine, dishwasher or tumble dryer than one or two-person households. For example, in the UK, while the average household size is 2.5 persons, the average household size owning a washing machine is 2.6, owning a dryer is 3.2, and owning a dishwasher is 4.2 persons, while the number of uses is dependent on household size (Figure 3). As an illustration, if the size of households owning an appliance were to decline to the current average (2.5), then the number of washing machine uses would decline by 4%, dryer use by 20%, and dishwasher use by 14%, assuming no other changes, such as the quantity of clothes washed per person.

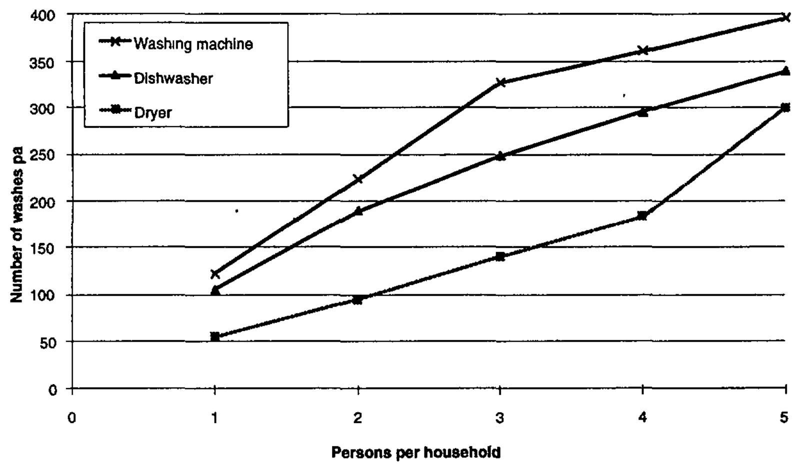

Figure 3 *Number of washes per annum by household size*
Source: Authors' analysis based on Market Trends (1993), Siderius (1995) 2, Silinpaa (1995)

4.2. Ownership dataFel! Bokmarket är inte definierat.

The main source of UK ownership data is the GfK Home audit and GfK Lek-Trak (for data on sales of new appliances from UK retailers). Home Audit data cover both ownership and new acquisitions based on interviews with a rolling sample of 20-25,000 households, scaled up to represent the UK by income group, tenure and household size. Ownership data can be disaggregated to examine trends in average size or features of new appliances bought, or ownership by household size, to examine the implications for energy consumption.

4.3. Technical data from test resultsFel! Bokmärket är inte definierat.

Technical data obtained under test conditions as laid out in the appropriate procedure (Table 1) are international and provide the basis for comparison between models, whatever the country of origin. Tests for some groups of appliances, for instance television and cookers, do not exist and limit both policies and studies on the efficiency of these appliance groups. Energy data can be stated two ways. As an energy efficiency (eg kWh/kg stated capacity) it is useful for comparing two appliances for the purposes of labels or standards. However, energy consumption (eg kWh/load) is a better descriptor for modelling total energy use by an appliance, and in the main, has been used in this paper.

Table 1 *Presentation of technical data on cold and wet appliances*

	Test procedure	consumption	efficiency
All cold appliances	EN 153	kWh/24hrs	kWh/litre adjusted volume/24hr
washing machines	IEC 456	kWh/load	kWh/kg stated capacity
dryers	IEC 1121	kWh/load	kWh/kg stated capacity
dishwashers	IEC 436	kWh/wash	kWh/place setting

In addition to data on the current market, there are several time-series of efficiency of appliances:

- DEFU has recorded efficiency of a range of models available on the Danish market since 1973 (Moller 1995) 4.
- The UK Consumers' Association has data on appliances tested (using their own procedure) between 1987 and 1994. The CA tend to test appliances as or before they are launched onto the UK market. Samples tested may not be representative of the entire market: in order to reduce this effect and in order to provide an indication of the range of products on offer, CA data for any one year has been taken as the average of the current and previous year.
- ZVEI (German appliance manufacturers association) has sales weighted data on the German market. Data were taken from manufacturers sales literature, and weighted according to market share. The data cover 77-90% of the market depending on product group, and 15 of 22 German manufacturers (Hass 1992).
- Limited data are available on technical change in the French market, especially Thomson machines, as reported by M. Robin (Despretz 1990).

The German data set is the most representative of the market, and has been used for developing underlying trends. Rates of change of technical efficiency gathered in one market cannot be assumed to be simply transferable to another. The two major factors in improving appliance efficiency are competition and legislation (Hinnells 1993). The German appliance industry has been developing within a different policy context to other markets, and efficiency has been affected by the availability of product lists, voluntary agreements on sales weighted average consumption, higher water prices. The competitive and legislative environment has led to a specific range of products on offer. The German voluntary agreement on improving appliance efficiency has not been renewed because of the uncertainties over technical developments of CFC and replacements as refrigerants, and "there was also no denying that, from the cost benefit point of view, it is becoming increasingly difficult to exploit the remaining energy saving potential" (Hass 1992).

The rate of change of efficiency is affected by the nature of competition between firms: competition in the appliance industry in the late 1970s and early 1980s was on reducing the purchase price of new machines, particularly with Italian manufacturers beginning to export on a large scale. Since the late 1980s, following a period of takeovers, competition within the industry has turned to adding value to machines, with an emphasis on reduced running cost (Mintel 1991). However, with care, trends may be transferable: the Austrian market is very closely allied to the German market, indeed most Austrian appliances are German imports. Sattler (1994) found that efficiency trends on the Austrian market follow those in Germany, by about three years. UK dishwashers appear to lag German dishwashers by about 5 years.

The technical data should be interpreted with care: first, consumption under test conditions is often not a good indicator of consumption in households, and secondly, there is enough latitude within the test procedure to lead to significant variation in reported energy consumption particularly when measured by consumers' organisations in comparison with manufacturers' stated data. To take just one example, the IEC 456 test procedure for washing machines specifies the water temperature going into the machine as 15°C +/- 5°C: thus it is legitimate to test anywhere between 10 and 20°C, though in households, inlet water temperature can fall to 5°C.

With regard to the variation between sources, analysis by ECU of the UK Consumers' Association (CA) database of cold appliances tested between 1987 and 1992, indicates that on average manufacturers stated consumption was lower than CA measured consumption by an average of 6% for fridge-freezers, and 10% for refrigerators. In some cases the CA tested consumption was 135% higher than manufacturers stated consumption. There appears also to be a difference between consumers organisation and manufacturers stated consumption for the wet appliances (Table 2). There is particular variation for tumble dryers, which is due to wide tolerances allowed under test conditions. These test conditions are in the process of being revised and tightened.

Table 2 *Comparison of a sample of consumption data on the 1994 EU market for wet appliances*

	Manufacturers data	Consumer Organisation data	Difference
washing machines (kWh/kg)	0.42	0.41	2.5%
dishwashers (kWh/place)	0.135	0.148	8.7%
air vented dryers (kWh/kg)	0.63	0.75	16%
condensing dryers (kWh/kg)	0.70	0.80	12.5%

Source: ECU analysis of unpublished GEA data

4.4. Appliance usage data

Usage data (ie the number of times or the amount of time an appliance is switched on, not kWh consumption) in the UK are relatively rare, though the UK Consumers' Association have commissioned some research (Market Trends 1993). Where data on the UK are missing, data from elsewhere in the EU can provide a surrogate, though there are important cultural differences between EU countries and absolute levels of use, or trends in use may not be transferable from one country to another.

Usage data have been collected from a variety of EU sources, usually consumers organisations (SWOKA in the Netherlands, Konsumentverket in Sweden, Work Efficiency Institute in Finland). DEFU (Danish electrical utilities research association) has conducted bi-annual surveys of usage since 1982. Sample size is around 600 for SWOKA, and 2000 for DEFU, though in each case, ownership of appliances in each group follows national average ownership: thus of the SWOKA sample, 120 households may own a tumble dryer. If the average household size of the sample varies, the data will vary.

4.5. Measured consumption data from households

Measurements of consumption (ie kWh) by individual appliances in households have been undertaken in the UK mainly by the Electricity Association (Allera 1994)5. However, measurement is limited in terms of history, representativeness of the population, and the range of appliances included. Until the mid-1980s data were based on a small number of households, and only recently has the EA begun to monitor 100 households in a more systematic way. The sample includes only those houses with more than 2000 kWh pa consumption in order to maximise the number of appliances present and monitored. Appliances measured include all the cold and wet appliances, cookers, electric showers and storage heaters. However, ownership data suggests that the wet appliances are more likely to be present in the larger than average families, and higher than average income groups. EA do not collect diary data on use patterns, partly because of the high drop-out rate within a sample over time. Thus it is not possible to disaggregate usage and technical trends from these data.

The Lothian and Edinburgh Environmental Partnership (LEEP) have been monitoring appliance consumption in 97 households for 18 months. These data are biased in the opposite direction from EA data, as they come from low-income households (only 3 of the households are economically active); ownership of dishwashers in the sample is zero, and the appliances may be older or less well maintained than average. EA and LEEP are consistent within +/- 8% with regard to cold appliances. There is a 16% difference in average consumption of washing machines, and a

53% difference in average dryer consumption (Table 3). The effect of income on appliance usage patterns appears, therefore, to be appliance specific and not uni-directional.

Table 3 *Measured consumption by cold and wet appliances (kWh pa)*

	Refrigerator	Freezer	Fridge-freezer	Washing machine	Tumble dryer	Dishwasher
EA average	**350**	**635**	**620**	**225**	**270**	**400**
LEEP average	**371**	**586**	**592**	**188**	**415**	**--**

Source: Allera (1994) 5 collected in 1992-3 and LEEP/ECU analysis measured 1994

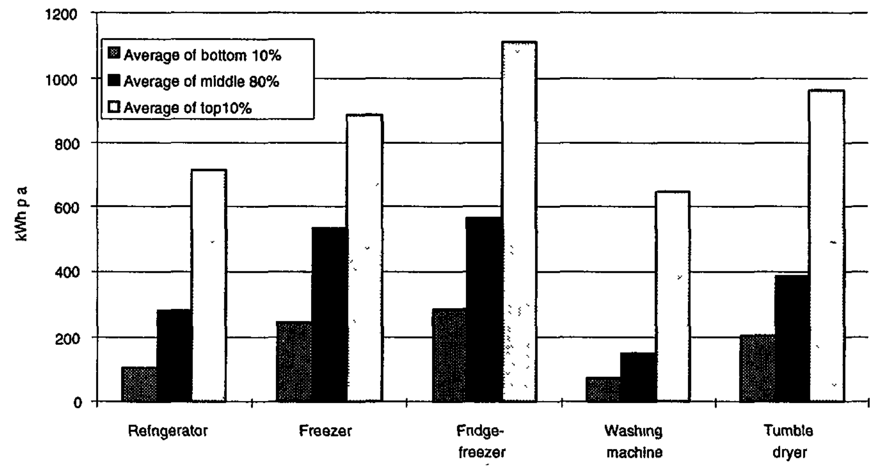

Figure 4 *Variation in measured consumption by appliances in Edinburgh, 1994*
Source: ECU analysis of LEEP analysis

There is considerable variation in consumption across the LEEP sample, with a factor of between four and ten in consumption between the bottom 10% and the top 10% of samples (Figure 4). Household size, differences in efficiency and state of repair of the appliance may all be factors causing this variation.

There are limitations to these measured data: they provide only a snapshot. Unless time-series data are available from a representative sample of the population (in terms of family size, social group, income group and occupancy levels), any looked for variation in technical efficiency or use patterns could be lost in variations within the sample. Measured consumption data will be poor in indicating changes in efficiency, size or features of appliances over time because only about 1/12 of the stock is replaced in any one year, and many other factors contribute to year-to-year variation.

Thus, in summary, trends in total consumption can be discerned from disaggregating

- demographic data,
- ownership, acquisitions and sales data, which give trends in appliance size and features,
- consumption under test conditions,
- usage data from diaries or surveys,
- and measured consumption in sample households.

These data are now discussed in relation to the cold and then the wet appliances, in order to determine the relative importance of each and the net effect on consumption

5. THE COLD APPLIANCES

Several factors impact changes in the total consumption from cold appliances including:

- trends in purchasing such as an increased volume of frozen space, in particular through combined fridge-freezers, and additional energy consuming features such as auto defrost,
- trends in patterns of use such as increasing ambient kitchen temperatures, and increasing numbers of fitted kitchens,
- technical trends such as improved efficiency of insulation and more efficient compressors.

5.1. Changes in size and features of new cold appliances

The most important trend is the change in purchasing patterns: ownership of refrigerators has declined from 78% in 1975 to less than 50% today. Combined fridge-freezers have replaced refrigerators, and almost 90% of households now own some form of freezer. In terms of energy consumption, any change in frozen space (at -18°C) is much more significant than a change in refrigerated space (at +5°C) since frozen space implies 2.15 times the energy consumption of cold space (GEA 1993 p34).

The average size of units sold changed over the years 1980-87: there was a 21.5% reduction in the average size of chest freezers, and 13.9% reduction in the size of upright freezers, which is a rate of change of 3% and 2% per annum respectively. From 1980-87, based on GfK data, there was no detectable change in the size of refrigerator. Also, the data available do not give trends in purchase of appliances with features such as auto defrost, which significantly affect energy consumption.

5.2. Use of cold appliances

Energy use on cold appliances might be thought to be relatively independent of use patterns, since they are switched on all year. However user behaviour can modify an apparently fixed energy consumption. Over 80% of the heat load for a refrigerator comes through the wall and doors. The remaining load is equally split between warm air infiltration and cooling of products placed inside the refrigerator (March Consulting 1990 p37).

The 80% is determined by ambient kitchen temperature, the flow of air around the refrigerator, and the quality of insulation. One way in which human decisions do modify the ability of a cold appliance to remove heat is the siting of appliances. Siting refrigerators next to heat sources (such as an oven or dishwasher) increases energy consumption by some 10-20%. An increasingly important trend appears to be the effect of fitted kitchens: enclosing refrigerators in fitted cabinets cuts off the flow of air around the appliance and may increase consumption by 10-90%, according to unpublished research by the Work Efficiency Institute in Finland (Silinpaa 1995) 3.

Cold appliance consumption is correlated with ambient kitchen temperature, and internal kitchen temperatures are linked to external temperatures. Proctor (1993) found that a 1°C increase in temperatures increase consumption by 1.8%, some units experienced a doubling in energy use when external temperatures rose from 18°C to 26°C. Given that the average annual temperatures can vary by over +/-1.2°C, consumption may vary by +/-2%. Perhaps more significantly, average temperatures recorded at weather stations in the Scottish Borders are consistently 3.5°C cooler than those recorded in Devon on the south coast: refrigerator consumption in Scotland may be 6.3% lower than in Devon. Variation across the EU will be significant.

The 20% of heat load that comes from air infiltration from door openings and from cooling of products put in the refrigerator varies with household size (Sattler 1994), and can vary by a factor of 1.8 across household sizes, even when removing the effect of size of appliance by a comparison in terms of kWh/100 litres (Figure 5).

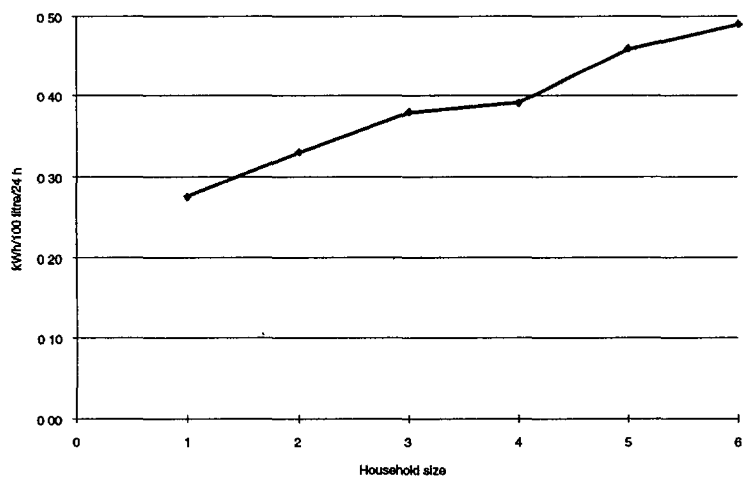

Figure 5 Refrigerator consumption according to household size
Source: Sattler (1994)

5.3. Changes in efficiency

Efficiency is defined as the energy consumption per unit service. No time series of efficiency is available for new appliances offered on the UK market, but a variety of data suggest a considerable improvement in efficiency of average EU new appliances. ZVEI data (Hass 1992) indicates a 33% improvement between 1978 and 1988, a net improvement of 3% pa, with a faster rate of change in freezers (3.5-5% pa) than for refrigerators (1-3% pa). The Group for Efficient Appliances used a Swiss database of manufacturers stated consumption under EN 153 (GEA 1993 p263). This showed a 1.5% pa improvement over the whole period 1960-92, but within this period there was a greater rate of change between 1985-92 (coinciding with the ZVEI data), when competition between manufacturers was focused on added value rather than price. Evidence from the Netherlands suggests that there was no change in efficiency during the period in which CFCs were phased out (van der Sluis and Weijers 1994), but following this, and the introduction of energy labelling, the 1-3% pa improvement could be expected to continue into the next century, given that refrigerator efficiency is a long way from any limits on technical efficiency.

Test consumption is not directly comparable with actual usage, since the test (EN 153) is conducted with an ambient temperature of 25°C, much higher than is typical of UK homes, and with no food load or door openings. The UK Energy Efficiency Office (EEO undated) has suggested that in the UK:

- for freezers, actual consumption is 85% of test consumption,
- for refrigerators, actual consumption is 77% of test consumption,
- for fridge-freezers, actual consumption is 79% of test consumption.

These conversion factors are important for estimating the total consumption of appliances, they do not affect rates of change over time.

5.4. Net effects on cold appliance consumption

A similar rate of change is apparent in the stock of appliances measured in the UK as is apparent in the average new appliance: measurements conducted by EA in 1982 and 1992 show an annual rate of improvement equivalent to 1.9% pa for freezers, and 1.5% pa for refrigerator-freezers (Allera 1994) 5. The life of a cold appliance in the stock is around 12-15 years. If the rate of improvement is constant, and if the test procedure is representative of actual consumption, the stock average will lag by about 6-7 years, or 10-20% less efficient than the average new. In Figure 6, average new consumption 1960-1992 is represented by the lines, and the stock average in 1982, 1992 and 1994 is represented by points (from Allera 1994) 5, and from LEEP.

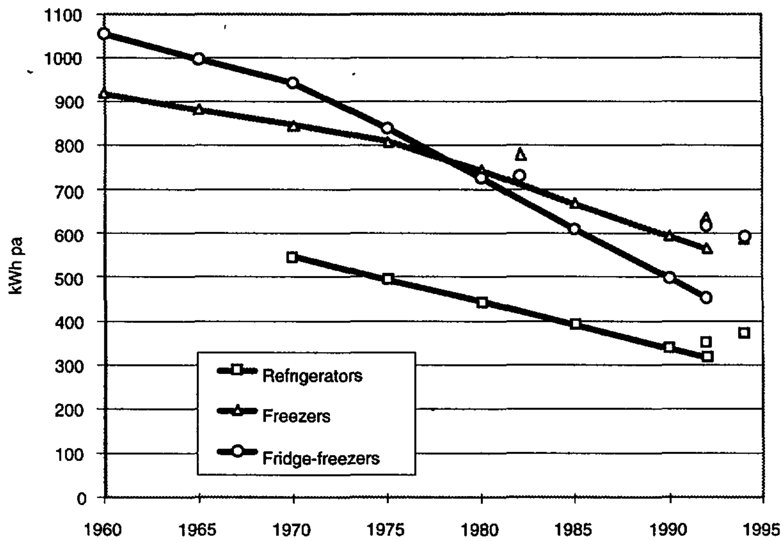

Figure 6 Cold appliance consumption
Source: ECU analysis of GEA, LEEP and EA data

Thus in summary,

- cold appliance consumption is temperature dependent and may vary by +/- 2% due to the effect of fluctuations in average annual temperature on ambient kitchen temperatures. Latitude and climate are also significant,
- refrigerator consumption is dependent on household size, especially from door openings and cooling warm food: a reduction of household size may imply some autonomous reduction in appliance consumption,
- energy consumption by new cold appliances has almost halved since 1960, mostly due to efficiency improvements equivalent to 1-3% pa, but reductions in freezer size has reduced consumption by around 8%, whilst some reduction has come from larder refrigerators replacing refrigerators with ice boxes,
- however, the most important trend in terms of the total electricity consumption is the massive increase in ownership of freezers and fridge-freezers: improvements in efficiency of cold appliances have been more than cancelled out by a large increase in frozen space.

6. THE WET APPLIANCES

The wet appliances are now examined and the case study is used to demonstrate the issues raised when making projections. The wet appliances are much harder to analyse than the cold appliances. The service is harder to define: rather than litres of cold space, the service offered by a washing machine is kilogrammes of clean clothes, but test procedures have to date been unable to define satisfactorily the service in terms of cleaning performance, rinsing performance, and creasing. The process of washing, rinsing, spinning and drying is more complex than maintaining a cabinet at a certain temperature, and with chemical and mechanical process acting together the number of possible variables is much greater.

6.1. Washing machines

Variables in washing machine consumption include:

- changes in use patterns, such as reduced temperature of washes (particularly reduced use of the 90°C wash), and an increasing number of washes, though both effects are thought to be close to saturation,
- technical changes such as a reduction in water and energy use, and increasing spin speed.

6.1.1. Washing machine use

The number of washes per household in Denmark has increased by 18% since the mid 1980s (Figure 7), despite reductions in family size. This is for a variety of reasons, from a changed perception of 'dirty' (we now wash more frequently with a lighter wash), to a reduction in the use of commercial laundry facilities and dry cleaning. However, this trend is thought to have saturated, especially in Denmark and Germany. The net effect of the possible saturation of this trend, together with a decline in household size, is not known. Therefore, the number of washes per annum is assumed to continue at about the present level. One exception to this may be Italy where there is currently a high number of washes done by hand.

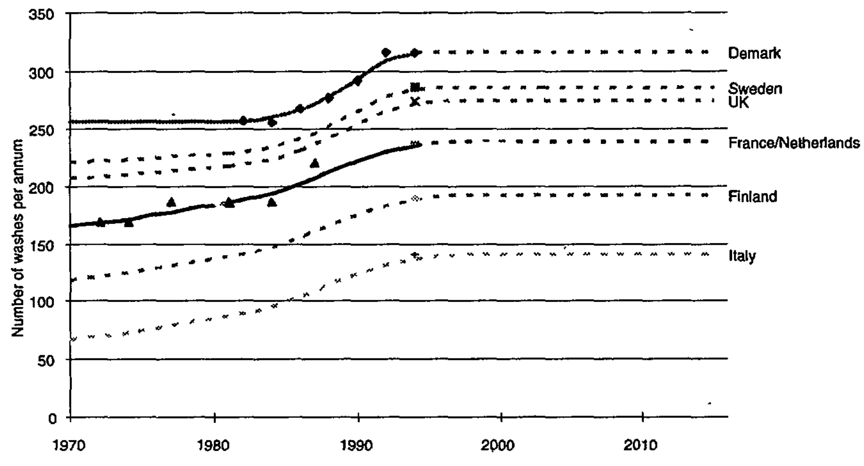

Figure 7 Mean number of loads washed, international comparison, 1970-2010
Source: Analysis based on a variety of estimates

At the same time, wash temperatures are falling, though the change is not uniform across the EU (Figure 8). In most countries, the use of a 90°C wash is declining except in Denmark, Austria and Italy, where use of the 90°C wash remains consistently high. In the UK, the number of 90°C washes has fallen to about 7%, while 52% of washes are at 40°C or lower (Market Trends 1993). Many countries are believed to be following the pattern measured in France (Lebot 1994)6 in that the percentage of 40°C washes is increasing. The reasons for these changes are various, and include: the development of low temperature detergents; increased use of disposable nappies (displacing especially the 90°C washes); and an increasing use of fabrics with mixed fibres.

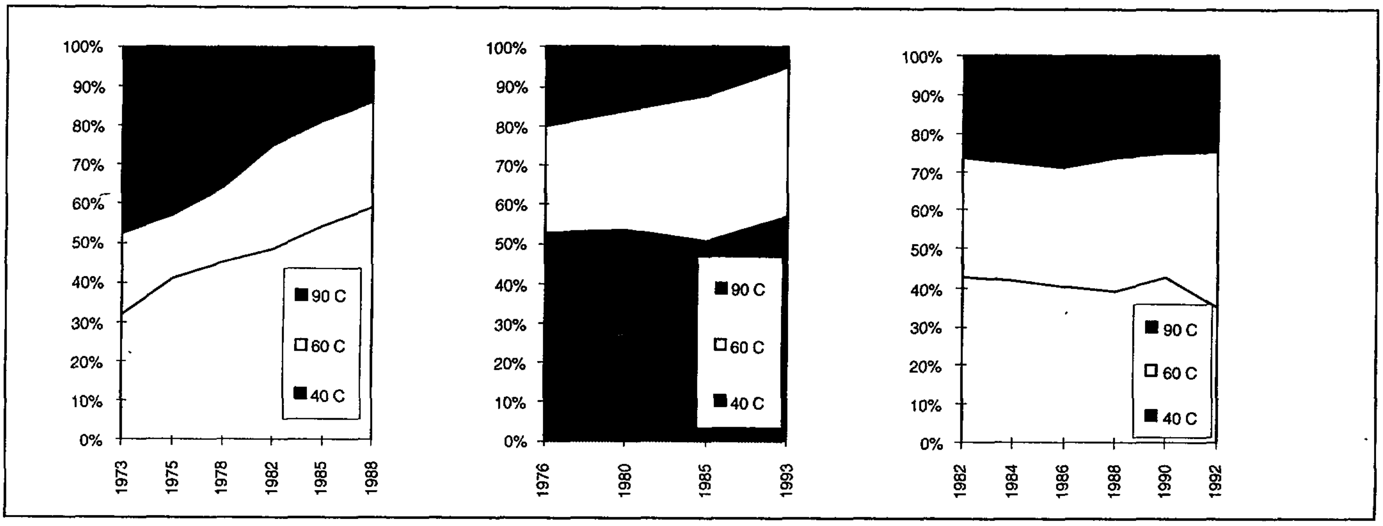

Figure 8 Percentage of washes at each temperature in France (left) Sweden (centre), and Denmark (right) Source: Lebot (1994) 6, Hedenskog (1995) 7 and Moller (1995) 4

6.1.2. Changes in efficiency

Figure 9 shows the average kWh per wash of a new appliance over time at 90°C, 60°C cotton, and 40°C (the top, middle and bottom lines respectively) based on a variety of sources. The lines are least squares lines (using a low pass filter), based on German sales weighted data (from ZVEI, in Hass 1992, shown as circles). Also plotted are Danish data (Moller 1995, shown as diamonds)4 and French data (Despretz 1990, shown as triangles).

There is a factor of 1.6 in energy consumption between the 5th percentile (most efficient) and the 95th percentile (least efficient) on the current EU market. The 95th percentile machines appear to be equivalent to market-average German technology in the early 1980s. Eliminating less efficient machines from the market is likely to require manufacturers to concentrate product development on redesigning the oldest machines. The French market appears to lag the German market by some 5 years, whereas the Danish market appears to be leading the German market.

Technical improvements since 1973 are a result of several factors: particularly, a 20% reduction in water consumption, less use of a pre-wash, and a reduction in the actual temperature of the wash (thus a 90°C wash may actually take place at 85°C). The underlying technical improvement is equivalent to a rate of change of 3% pa in the mid-1980s, which has halved in the mid-1990s, and may halve again by 2005: any technical improvement may therefore be saturating without policy intervention, and assuming no radically new technology.

If we were to assume these historic rates of change were to continue, the average on the market would go beyond the current market best, and at some point would go beyond the theoretical limit. The assumption is, therefore, that by 2016, the average new appliance will saturate at the upper 5th percentile of the current EU market. A smoothed curve is then fitted between these known and interpolated data points. Where historical data is not available, and in order to reproduce the base case technical data for any one country, the curve is then moved backwards or forwards through time, until the curve matches the known data point for 1993/4.

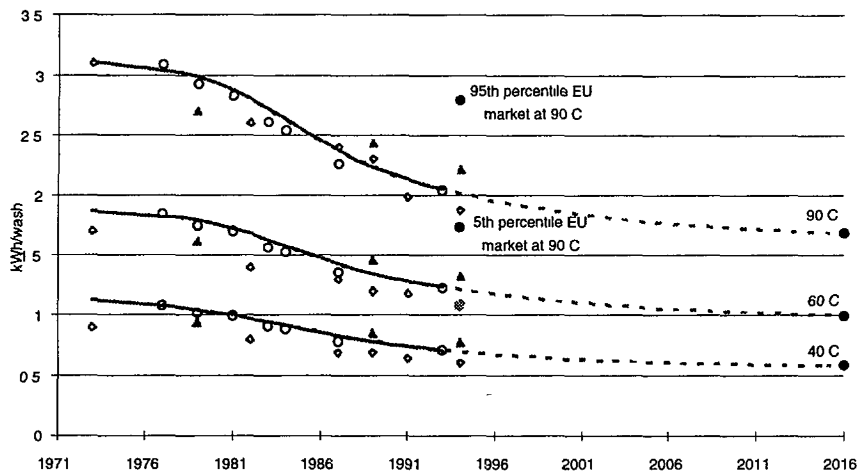

Figure 9 *Trends in washing machine consumption (based on test results under IEC 456)*
Source: ECU analysis of ZVEI and other data. See text for explanation

An important element in washing machine consumption in the UK is the high level of ownership of hot-fill: 92% of machines in the UK take in both hot and cold water supplies, whereas 90% of machines in the EU use cold fill only. Tests were performed on 30 washing machines in 1993/4 using a 2.5 kg load (found by CA to be typical of actual load conditions). The results do not differ markedly from another 34 machines tested between 1990 and 1993, using manufacturers stated load. It was found that hot fill reduces electricity consumption in the machine itself by an average of 29% (Table 4). The energy involved in heating the water, external to the hot-fill machine, is not included in the calculation. The reason for the dominance of hot fill in the UK is the high penetration of gas central heating and hot water heating. Thus an improvement in efficiency in the UK would save gas rather than electricity.

Table 4 *Electricity consumption (kWh/load) of hot and cold fill washing machines*

	60°C	50°C	40°C
Average cold fill	**1.14**	**0.71**	**0.52**
Average hot fill	**0.80**	**0.51**	**0.37**
Difference	30%	28%	29%

Source: ECU analysis of UK Consumers' Association data.

6.2. Tumble dryers

There are several variables which affect energy consumption of tumble dryers, including:

- changes in use patterns which in some countries may have saturated,
- technical changes such as increasing spin speeds on washing machines mean clothes have a lower moisture content when they go into the dryer,
- increased ownership of condensing dryers and washer dryers which implies increased consumption, and
- little discernible change in efficiency of dryers over time.

6.2.1. Tumble dryer use

There are little data on the number of uses per annum of tumble dryers over time. The only known time-series is in Denmark, where there has been an increase in the number of uses of about 3.5% pa between 1982 and 1994 (Figure 10). Tumble dryer use may be influenced by several factors in different ways:

- changes in the number of washes may produce changes in dryer use (where households own both machines),
- declining household size, and increasing penetration of dryers in smaller households may cause a long term reduction in the average use,
- use may be dependent on climate, especially rainfall, and therefore subject to annual variation,
- use may be energy-price elastic, particularly in low-income households.

There are insufficient data to draw any conclusions, let alone to demonstrate a causal relationship. The average of all known data points in the EU is 160 uses per annum. Since consumption has varied for unknown reasons the safest forecast seems to be to project the current number of uses into the future. There are no known measured data from southern Europe: usage is likely to be lower due to dryer climate.

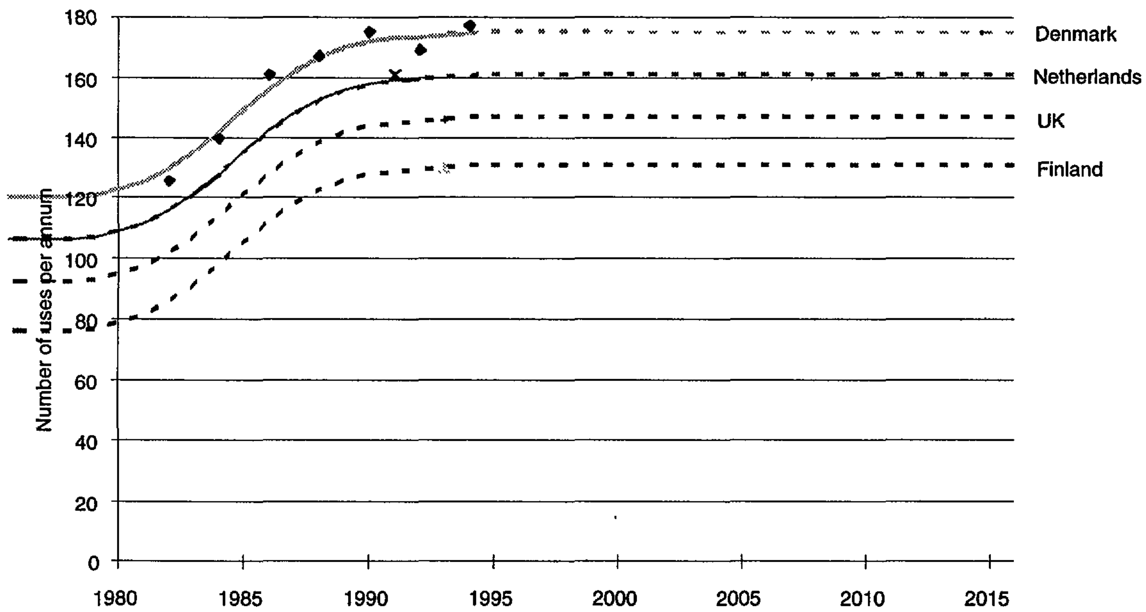

Figure 10 Tumble dryer uses per annum, 1980-2016
Source: Moller (1995) 4 and van Dijk and Siderius (1992)

The test procedure for tumble dryers (IEC 1121) is a poor guide to actual energy consumption since in the test procedure the time to dry is controlled by moisture sensors (rarely present in actual machines). Under test conditions, where moisture content is reduced to zero, the average length of time to dry is 94 minutes, and an average consumption per load of 3.13 kWh. There are no data on how long people leave their tumble dryers on for in practice, where the time to dry is often set by the user. A best estimate is around an hour (assuming consumers under-load machines, and assuming only about 70% of loads are dried to cupboard dryness, and the rest are only iron dry). Actual consumption per load may be less than 2 kWh.

One of the main determinants of tumble dryer time is the remaining moisture content of the clothes when they are put into the dryer, and this in turn, is related to average washing machine spin speeds: moisture content is inversely proportional to the spin speed of the washing machine. A simple regression analysis on CTTN (French centre for washing testing and technology) data shows that for every 100 rpm increase in spin speed, remaining moisture content declines by about 3.5%. Average maximum spin speeds are increasing: from 700 rpm in 1980 to an expected value 1400 rpm by 2010 implying a 26% reduction in remaining moisture content over this period, and thus in drying time, for the same load: thus a 1 hour drying time would be reduced to 45 minutes. Increased maximum spin speeds will also increase the amount of creasing which may result in an increase in the amount of ironing.

6.2.2. Changes in efficiency

It is difficult to assess changes in efficiency of tumble dryers. There are less data than for dishwashers or washing machines: the only time series available is 47 machines tested by the UK Consumers' Association between 1987 and 1993 on dry cotton, iron-dry cotton and easy care fabric cycles. There does not appear to be any improvement in efficiency over time, from these data.

6.3. Dishwashers

There are several variables which affect energy consumption of dishwashers, including:

changes in use patterns include a reduction in use from smaller households, more eating out, more pre-prepared food, fewer cooked breakfasts, lower daytime occupancy with midday meals.

technical improvements include reduced water use, but no reduction in temperature.

6.3.1. Dishwasher use

Little is known about usage patterns of dishwashers. Use may be expected to decline, given a decline in household size over time, and increased penetration of dishwashers in smaller households. In Denmark the number of uses has been measured every other year between 1982-92 (Moller 1995)4. Use varies around an average of 222 washes per annum. A least squares line through the Danish data suggests only a 4% decline in the number of washes over the forecast period to 2016 (Figure 11). In the UK the average number of uses (ownership weighted) is 254 washes pa. Data are particularly lacking on the split of wash temperatures, and the change in wash temperatures over time. A survey in Holland (van Dijk & Siderius 1992) suggests that 70% of washes are at 65°C and 30% of washes are at 55°C, while in Finland (WEI 1993), the split is 61% to 39%. An EU average split of 66%-33% has been assumed for the UK

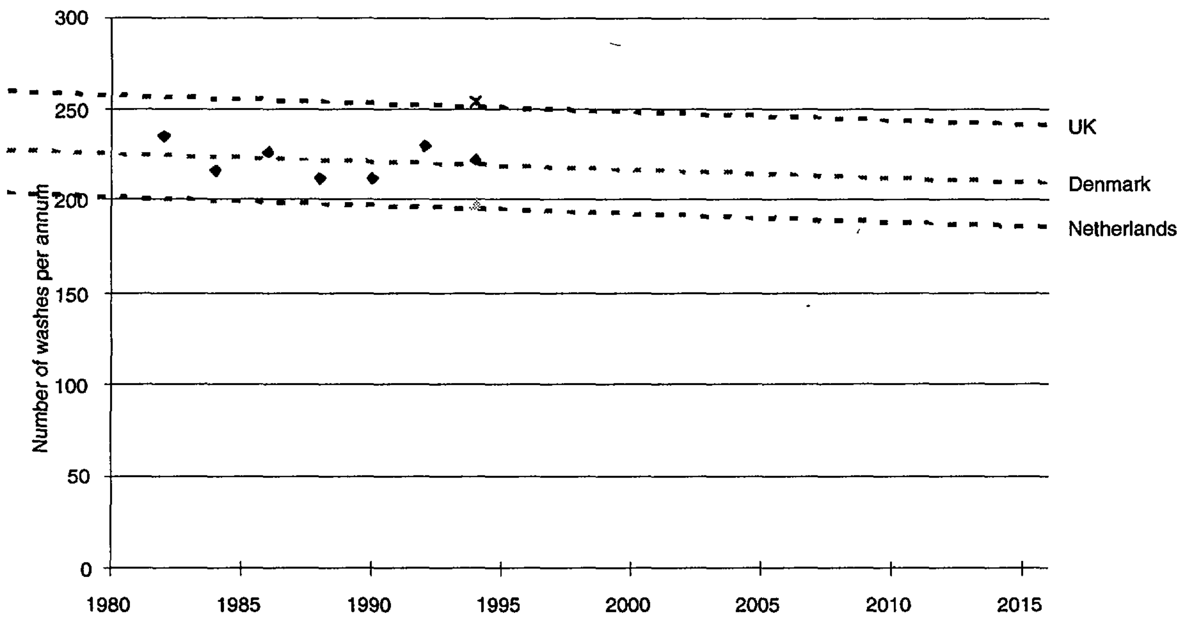

Figure 11 Dishwasher uses per annum, 1980-2016
Source: Moller (1995) 4 and van Dijk and Siderius (1992)

6.3.2. Changes in efficiency

Figure 12 plots technical data from DEFU (represented by the diamond symbols), ADEME (triangles), ZVEI (circles), and UK Consumers' Association (crosses) which indicate a reduction in the energy per wash. ZVEI claim a 36% improvement in the sales weighted efficiency of dishwashers sold on the German market between 1978 and 1988 (3.6% pa). Consumers' Association data in the UK indicates a decline of 0.17 to 0.13 kWh/place setting for average new machines between 1985 and 1994, a decline of 23% in 9 years (2.5% pa). These figures are for larger machines only (10-14 place settings). There is little information on smaller machines (4-6 place settings) which have a higher kWh/place setting, so they have been excluded from the analysis.

The UK and French markets appear to lag the German market by 5-7 years, while the Danish and German markets appear to be very close. As with washing machines, the 95th percentile machines are equivalent to average German technology in the early 1980s. The same assumption is made as before, that by 2016, the efficiency of the average new appliance will be equivalent to the upper 5th percentile of the current EU market. A smoothed curve is then fitted between these known and interpolated data points. The underlying rates of change are forecast as follows. Where historical data are not available, and in order to reproduce the base case technical data for any one country, the curve is moved backwards or forwards through time, until the curve matches the known data point for 1993/4.

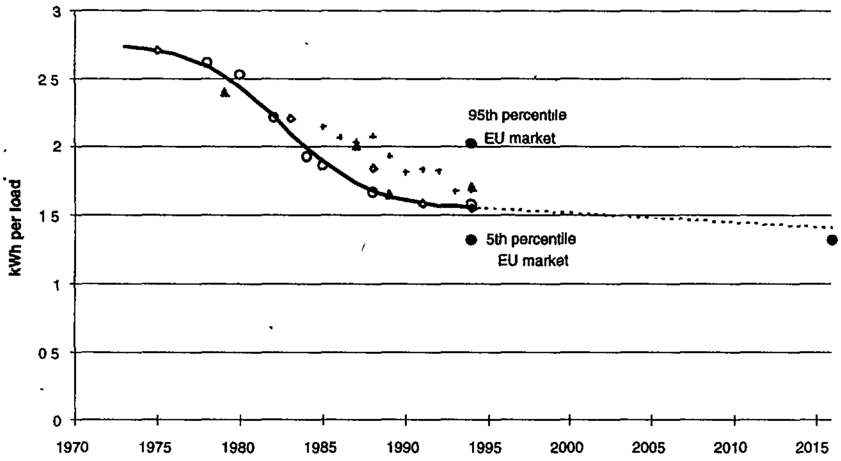

Figure 12 Improvements in efficiency of dishwashers
Source: ECU analysis of ZVEI and other data. See text for explanation

6.4. Net effects on wet appliance consumption

Taking into account both technical and usage changes, calculated UK wet appliance is of a similar magnitude to recently measured figures from the Electricity Association. Data from the Lothian and Edinburgh and Environmental Partnership (LEEP) demonstrates a wider variation.

- For washing machines, measured consumption under test conditions has improved by 30% at 90°C, while wash temperatures have declined through time, and the number of washes has increased, resulting in a calculated consumption of 189 kWh. Given the high ownership of hot fill machines in the UK, consumption is about 25% below the EU average. LEEP measured consumption averaged 188 kWh. EA measured consumption averaged 225 kWh pa,
- for tumble dryers, the number of uses has increased over time. There is no evidence that the efficiency of tumble dryers has improved, although increasing washing machine spin speed implies reduced moisture content of clothes going into a dryer and therefore lower energy consumption. The best estimate for the UK is 160 uses per annum using 265 kWh. Measured LEEP consumption averaged 415 kWh (though from only 18 samples), and EA averaged 270 kWh pa. There is good cause therefore to treat tumble dryer technical and usage data with a great deal of caution: estimates are sensitive to many factors,
- for dishwashers, there has been a reduction in consumption per load of about 36%, to 1.56 kWh, and a slight decline in the number of uses (currently 254 uses per annum). Calculations indicate 398 kWh pa currently, with consumption estimated to have declined from 700 kWh pa. EA data averaged 400 kWh in 1992.

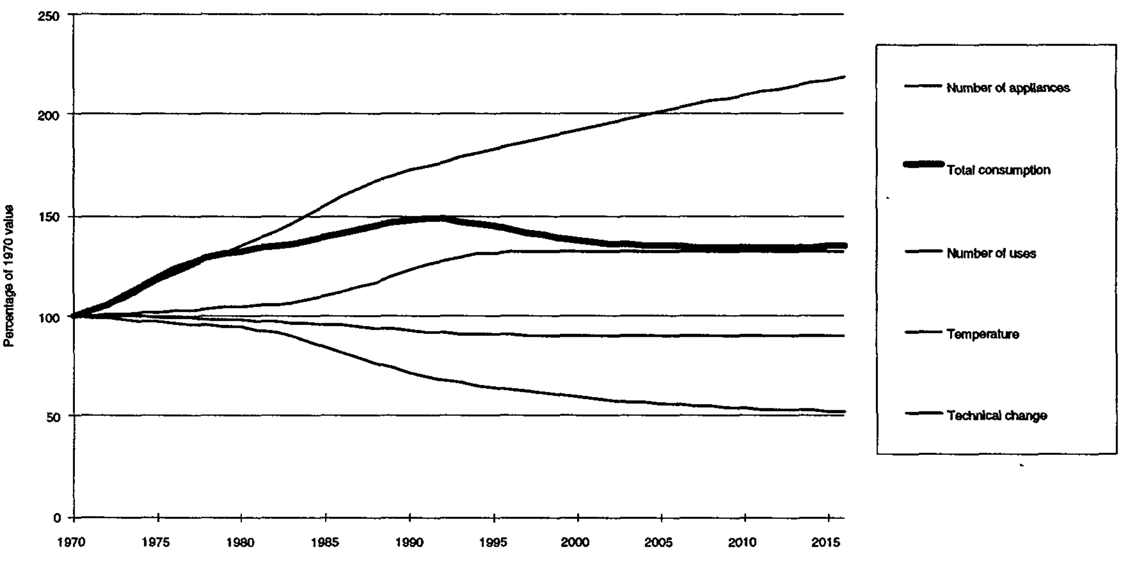

Figure 13 Components of change in energy consumption by washing machines, UK 1970-2016
Source: ECU analysis

Examining the analysis on washing machines further (Figure 13), the changes, using 1970 as a base year, reveal some interesting features:

- a larger number of appliances, more than double,
- an improving efficiency with time,
- increasing level of service (ie number of washes),
- and a reducing temperature washes

All of these factors combine to result in a levelling off and slight decline in total consumption by UK washing machines after the year 1992.

7. CONCLUSIONS

This paper examines the relative importance of technical and behavioural factors in the use of cold and wet appliances, drawing evidence from demographic trends, surveys of usage patterns, test consumption data and load monitoring. Trends are important in developing a base case projection for 'no-intervention' as the baseline for estimating the actual savings from policy aimed at market transformation. A good understanding of the trends underlying past consumption help identify the potential savings to be achieved from policy intervention as well as indicating the type of policies most likely to be effective.

The paper shows that since 1970 in the UK:

- there has been considerable technical improvement: consumption under test conditions has improved by 30-50% for all of the appliances examined except tumble dryers, and wash temperatures have also declined due to improved detergents,
- the increasing number of households implies continued growth in the total number of appliances.
- consumption for both cold and wet appliances is related to household size. Intuitively, a reduction in household size should lead to a reduction in use. However, from historical data, the increase in service has been taken despite a declining household size. This conflict between the effect of household size at a point in time and the opposite trend over time has yet to be eplained,
- technical improvement in the cold appliances has been largely wiped out by an increase in the level of service; mostly as an increased volume of frozen space,
- technical improvements and reduced wash temperatures have more than offset the increase in the number of washing machines and increased service (ie number of washes)

The products examined here are products with a defined cycle (eg a 40°C wash cycle), or are on all the time (eg a freezer), and have a distinct test procedure. Other products such as cooker hobs or televisions, have a power demand (kW) which is easy to determine, but a use pattern which is much harder to establish, and which changes through time under the influence of a much wider set of changes within society. Savings from intervention would be that much more difficult to quantify. Usage - especially of those appliances with no fixed cycle - is likely to be dependent on other less tangible variables, and may indeed be influenced by household income levels, or energy prices.

Policy has tended to focus on improving the technical efficiency of appliances bought by consumers. However, not all of the technical improvements result in reduced consumption: an improvement in efficiency has been taken as an increase in service. Indeed, improvements in building shell efficiency, and improvements in motor vehicle efficiency have in the past been taken as increases in service (Shorrock and Bown 1993, Hughes 1993). If the aim of policy is to reduce consumption rather than just improve efficiency, there needs to be a focus on behavioural issues as well as technical factors. The powerful effect of both more households and greater ownership can be offset by the more rapid diffusion of efficient appliances onto the market, through information, labels, rebates and minimum standards. The effective reduction in total consumption will also depend on harnessing positive behavioural trends (cooler washes) and discouraging extra levels of service (more washes).

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9. ENDNOTES

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